Project Title: Quantifying lock and dam passage, habitat use, and survival rates of invasive carps in the Ohio River Basin

Geographic Location: The Ohio River basin from Olmsted Pool (RM 964.4) to Willow Island Locks and Dam (RM 161.7), including tributaries. The Wabash River from Terre Haute, IN downstream to the confluence with the Ohio River. White River from Indianapolis, IN downstream to the confluence with the Wabash River.

Lead Agency: U.S. Fish and Wildlife Service **(**USFWS)

Participating Agencies: Southern Illinois University (SIU), Eastern Illinois University (EIU), Indiana Department of Natural Resources (INDNR), Illinois Department of Natural Resources (ILDNR), Kentucky Department of Fish and Wildlife Resources (KDFWR), Ohio Division of Wildlife (ODOW), West Virginia Division of Natural Resources (WVDNR), Ecosystem Connections Institute (ECI)

Statement of Need: Silver and Bighead Carp (*Hypophthalmichthys molitrix* and *H. nobilis*, respectively), herein referred to as "invasive carps", are invasive fishes within the Mississippi River Basin. Since they were first detected within the Mississippi River Basin in the early 1980's (Freeze and Henderson 1982; Jennings 1988; Robison and Buchanan 1988; Burr et al. 1996), the range of invasive carps has expanded to include much of the mainstem of the Mississippi River as well as other large rivers within the Mississippi River Basin (e.g., the Ohio, Missouri, and Illinois rivers) (Burr et al. 1996; Garvey et al. 2006; Camacho et al. 2020; Schaick et al. 2020). This rapid expansion throughout the Mississippi River Basin is likely due, at least in part, to rapid population growth resulting from high individual growth rates, short generation times, high fecundity, a protracted spawning period, and long-distance dispersal capabilities (Garvey et al. 2006; Peters et al. 2006; DeGrandchamp et al. 2008; Lenaerts et al. 2021).

Invasive carp populations are established throughout the lower and middle reaches of the mainstem Ohio River as well as many of its tributaries and successful reproduction is suspected as far upstream as Cincinnati, Ohio. The establishment of these populations and the potential for invasive carp populations to expand their range into the upper Ohio River has led to concern among natural resource managers that invasive carps might gain access to the Great Lakes Basin through tributaries of the Ohio River. If invasive carps were to gain entry to the Great Lakes, they could cause substantial ecological and economic damage by disrupting food webs (Sass et al. 2014; Collins and Wahl 2017) and commercial and recreational fisheries (Pimentel et al. 2000, 2005). Because of the ability of invasive carps to cause extensive economic and ecological damage, limiting the expansion of invasive carp populations into novel habitats is of the utmost concern.

To prevent the spread of invasive carps into the upper portions of the Ohio River basin and potentially into the Great Lakes, we must understand their propensity for upstream movement, habitat use, and the probability of among-pool transitions. These monitoring efforts will reveal the timing and conditions most likely associated with pool transitions and entry into novel habitats. Additionally, mass movements to "preferred" habitats may reveal the timing and locations of spawning aggregations. Knowledge of these movements will be used to create management strategies designed to limit population expansion and inform management actions such as mass removal efforts.

Project Objectives:

1) Quantify movement probabilities among navigation pools within the Ohio River, between the Wabash and Ohio rivers, and between the Wabash and White rivers.
2) Understand movements among tributary and mainstem habitats within the Ohio River basin in response to environmental conditions and commercial harvest.
3) Inform invasive carp removal efforts by quantifying fine-scale habitat use and how habitat use changes through time in the Wabash and White rivers.

Project Highlights:

- Five-hundred, seventy-two Silver Carps were tagged during 2024 in the mainstem Ohio River (n = 502; J.T. Myers – McAlpine pools) and the Wabash River (n = 70).
- During the course of this study, ~77% of Silver Carps have inhabited tributaries compared with ~55% of Silver Carps detected in mainstem habitats.
- Estimated mean monthly pool-to-pool transition probabilities were generally low (< 0.2) for Silver Carps, suggesting that most of these fish remain within the pool in which they were tagged.
- Historical analysis of receiver data for tagged Silver Carps in the Wabash suggests that detection probability of tagged fish is > 80% with > 97% annual survival.
- Active tracking of Silver Carps in the Wabash River showed that habitat selection is not sex-specific indicating that targeted harvest will likely have similar effects on sex ratios.

Methods:

Ohio River

Acoustic telemetry was used to determine the probabilities of survival, detection, lock and dam passage, and movement between tributary and mainstem habitats of invasive carps in the lower to middle Ohio River (Olmsted to R.C. Byrd pools but primarily focused from J.T. Myers to R.C. Byrd pools). To do this, the locations of individual invasive carps tagged with VEMCO, Model V16 acoustic tags were recorded using a stationary array of VR2 receivers. Receivers were placed either within the mainstem Ohio River, the lower reaches of select tributaries, or lock and dam (L&D) structures. Within some tributaries, multiple receivers were deployed from the mouth to several miles upstream. This arrangement of receivers allows for the interpretation of upstream and downstream movement of tagged carps and improves our ability to assess tributary use as well as the timing of entry into and exit from tributaries throughout the year. For L&Ds, at least four VR2 receivers were deployed at each L&D to record pool-to-pool transitions through the lock chambers with the exception of Markland and R.C. Byrd L&Ds. During 2024, three receivers were deployed at Markland L&D, one at the downstream approach and two in the lock chamber. For R.C. Byrd L&D one receiver was deployed at the upstream approach and two were deployed in the lock chamber. For all other L&Ds, two receivers were placed within the lock chambers and at least one receiver was placed on each of the downstream and upstream approach walls. These receivers provide consistent spatial coverage across L&Ds to ensure detection capabilities are similar at each location and increase confidence in interpretation of detection data.

Acoustic Receiver Array: During August 2023 – July 2024, the receiver array extended from river mile 937.0 in Olmsted Pool, ~20 miles downstream of the Smithland L&D, upstream to Willow Island Pool (river mile 159.3) and included receivers in portions of the Wabash, Tennessee, and Cumberland rivers (Figure 1). During non-winter months, detection data were downloaded from receivers bi-monthly or as often as possible.

Acoustic Transmitter Tagging: Adult invasive carps were collected via boat electrofishing. Efforts were concentrated in areas where invasive carps are known to congregate such as side channels, backwaters, and tributaries. Fish were measured for total length (mm) and weight (g), and visually or manually sexed (if possible). Following these measurements, an acoustic transmitter (Vemco, Model V16-6H; 69 kHz) was implanted into the peritoneal cavity via a ~3 cm incision in the ventral musculature. The incision was closed with two or three sutures. The V16-6H transmitters provide individual identification and are nominally programmed to transmit a signal every 40 seconds yielding an expected battery life of ~1,460 days (4 years). Fish implanted with acoustic transmitters were also tagged externally using a lock-on tag inserted posterior to the dorsal fin (Floy Tag & Manufacturing, Inc. FT-4 Lock-on tag with clear over-tubing).

Tributary Use: To assess tributary use by Silver Carps (Bighead Carps were omitted due to a paucity of data), the proportion of detected Silver Carp in each habitat was determined by dividing the number of individual Silver Carps in each habitat by the total number of detected individuals June 2013 – July 2023. Additionally, to determine if specific tributaries may be of increased importance to Silver Carps, the number of individual Silver Carp detected in a tributary was divided by the total number of Silver Carps detected in that pool. Lastly, the time spent between transitions from tributary to mainstem habitat and vice versa was determined for each species as the mean number of days between detections in these two habitat types.

Pool-to-Pool Transition Analysis: To determine the probabilities of transitions among pools, survival, and detection of Silver Carps in the Ohio and Wabash rivers, a Multi-state with Live Recaptures analysis was conducted in Program Mark (Cooch and White 2008) using the RMark package (Laake 2013) in R version 4.1.2 (R Core Team 2021). In this analysis, the Wabash River and each navigation pool of the Ohio River are considered "states". Because environmental data (e.g., temperature and gage height) were included in this analysis and were collected from January 2014 to July 2024, detection data prior to January 2014 were omitted. Encounter histories were constructed for each individual by determining the pool within which an individual was detected most during each month (January 2014 – July 2024). Because tagging took place at various times throughout the duration of the study period and the expected battery life of the acoustic transmitters is ~4 years, not all individuals have a complete encounter history (maximum of 127 possible time periods). Encounter histories of tagged carps that were harvested during the study period were right-censored. This process removes these individuals from the estimation procedures for the times following harvest. Additionally, transition probabilities were estimated only for adjacent pools because there were very few detected movements among non-adjacent pools. Transitions among non-adjacent pools were, therefore, fixed to 0. Due to the small number of fish tagged (n = 46) and tags currently active in the Ohio River (n = 1), Bighead Carps were not included in these analyses.

To examine the effects of environmental conditions on the survival, detection, and transition probabilities of Silver Carps in the Ohio River, daily water temperature and gage height data were collected from U.S. Geological Survey gage stations from Olmsted to R.C. Byrd pools as well as the Wabash River (Table 1). Data were collected for January 1, 2014 – July 31, 2024. Because the focus of this analysis was on transitions among spatial states, only data from mainstem and Wabash River gage stations were used. Because gage data were not available for the Tennessee and Cumberland rivers, the gage data from Olmsted Pool were used for these areas. Temperature data were only collected at four gage stations in the sampling area but were consistent among these gage stations. An overall mean monthly temperature was, therefore, calculated for the mainstem Ohio and Wabash rivers using data from these gage stations. In contrast, all selected gage stations collected gage height data (ft) during the study period allowing pool-specific monthly mean gage height data to be calculated. To do this, gage heights were first converted to meters then the monthly mean gage height was calculated using all gages within a pool. Because monthly mean gage heights were highly variable among pools, these values were standardized within each pool by subtracting the mean and dividing by the standard deviation. Standardizing these data effectively places gage heights for all pools on the same scale, making comparisons more meaningful. After calculating standardized monthly mean gage heights, the time series for J.T. Myers, and R.C. Byrd pools were still incomplete. The methods used to complete the time series varied for each of the pool as a result of where in the time series gaps occurred and each pool's location in the river. For R.C. Byrd Pool (the farthest upstream pool for which data were collected), there were no gage height data collected during April 2017. To complete this time series, linear interpolation was conducted between March and May 2017. For J.T. Myers Pool, there were no gage height data from January – September 2014. Because this is the beginning of the time series, temporal interpolation within J.T. Myers Pool was not possible. Data from the pools directly upstream and downstream (Newburgh and Smithland pools, respectively) of J.T. Myers Pool were, therefore, used to spatially interpolate the missing data for each month using linear interpolation.

In addition, headwater and tailwater gage heights were provided by the U.S. Army Corps of Engineers to estimate the number of open river days at each Lock and Dam throughout the study period. Open river days were defined as those days that had a mean head height ≤1.5m (Fritts et al. 2024) To calculate mean head height, 30-60 min measurements of tailwater gage height were subtracted from headwater gage heights and used to calculate a daily mean head height. The number of days within each month for which mean head height was ≤1.5m were then summed to determine the number of open river days at each L&D.

These time series of temperature, gage height, and open river days as well as the encounter histories of individual Silver Carps were used to inform transition, survival, and detection probability estimates in multi-state models. Potential model structures included spatially and temporally invariant parameters, parameters that varied temporally (by month or season) and/or spatially (by pool), and parameters that varied with environmental conditions (e.g., mean temperature and standardized mean gage height). In addition, additive and interactive effects of covariates were considered. Due to the large number of potential model structures, a hierarchical model selection approach was used (Doherty et al. 2012). In this approach, detection and transition probabilities were held constant while the effects of month, season, and mean temperature on survival probability were evaluated (Table 2). After determining the best supported structure for survival probability, it was retained while evaluating the effects of month, season, standardized median gage height, pool, the number of receivers per pool and the number of receivers per river mile in each pool on detection probabilities (Table 3). Lastly, the best supported structures for survival and detection probabilities were held constant while evaluating the effects of month, standardized median gage height, monthly open river days, and pool on transition probabilities (Table 4). Models that did not converge are not presented in model selection tables. Models were compared using Akaike's information criterion corrected for small sample size (AIC_c; Burnham and Anderson 2002) to find the most parsimonious model. Akaike weights (W_i) were also calculated to examine uncertainty in model selection (Burnham and Anderson 2002).

Wabash River

Acoustic Receiver Array: During 2024, 18 receivers (Innovasea VR2Tx) were deployed in the Wabash River, and an additional two were deployed in the White River. These 20 receivers added to the existing network of 28 and 10 receivers in the Wabash and White Rivers, respectively (Figure 2). During 2024, only 7 receivers were recovered during July; the remainder were buried under the substrate or inaccessible to boats, despite changes to deployments by attaching them to river shoreline with cables. Low water during summer and fall 2024 made retrievals challenging.

Acoustic Transmitter Tagging: Tagging of invasive carps in the Wabash River follows the methods for the Ohio River, above. A total of 537 Silver Carp have been tagged since 2021 at multiple locations in the Wabash River. Tagging during 2024 was delayed by low water levels during spring and summer. EIU assisted in tagging efforts alongside SIU during fall 2024. Twenty tags were implanted in Silver Carp in Vincennes, IN on 11/18/24 and 50 tags were placed in Silver Carp in Terre Haute, IN on 11/19/24 for a total of 70 silver carp tagged in the Wabash River (Figure 3). An analysis of historical data from 2011-2018 for Silver Carp tagged in the Wabash River was conducted to determine the survival and detection probabilities. Detection and survival probabilities were determined using a longitudinal Cormack-Jolly-Seber model of acoustically tagged adult Silver Carp during 2011 through 2018 in both rivers, which is a unique approach only possible with long-term data from individual fishes.

Active Tracking for Habitat Use: Fine-scale habitat selection by tagged adult Silver Carps was assessed by EIU throughout the Wabash and White Rivers during 2021-2024. Monthly active tracking events occurred throughout the 305 rkm from Terre Haute, IN to the confluence of the Ohio River and the lower 105 rkm of the White River from Maysville, IN to its confluence with the Wabash River in Mt. Carmel, IL. During active tracking, the boat was maneuvered downstream while towing an omnidirectional hydrophone (Vemco VH165). Once a transmitter was detected, the fish's position was triangulated by using a submersible directional hydrophone (Vemco VH110). Habitat characteristics including macro-habitat type (channel border open, inside river bend, outside river bend) and micro-habitat type (log jam, rip-rap, run, thalweg) were recorded at each fish's location.

Beginning in May 2024, the invasive carp active tracking project was taken over by a new EIU graduate student. In the same month, macro-tracks were conducted on the Wabash and White rivers with one fish detected between the 40 combined river miles covered. During June 2024, an extended macro-track was conducted over 240 river miles, targeting the entire sampled reach of the Wabash River to determine the locations of tagged fish. Six individuals with tags belonging to SIUC were detected during this track, all located between Mt. Carmel, IL and New Harmony, IN. Micro-tracking was attempted at New Harmony during July 2024 but had to be cut short due to inclement weather. A macro-track of the upper reach of the White River was also attempted but also had to be cut short for the same reason, in addition to boat failure. During August another micro-track was conducted. It was determined that hour-to-hour assessment of movement between habitats (re-detection) is unfeasible due to logistical constraints (amount of distance that can be covered in the allotted time and variability in detection rates). Therefore, micro-track techniques will be refined to better assess fine-scale movements throughout the course of the day. Current plans for these refinements are to conduct future micro-track field tests that split reach runs into 3 time-of-day categories (morning, mid-day, evening), then re-tracked at each time category of the same day.

Invasive carp movement and distribution following dam removal

In November 2021, two dams were removed from the Eel River at river kilometer (RKM) 2. The largest of these two dams was 435-feet long and 9-feet tall and served as a barrier to invasive carp movement further up the Eel River. Removal of these dams created a novel opportunity to better understand invasive carp establishment in newly accessible habitat and evaluate the ecological risk of invasive carp occupancy in comparison to the ecological lift of new native species establishing in the Eel River basin.

Twenty-two sample sites were established to verify presence or absence of invasive carp species and to score each site using the Index of Biotic Integrity (IBI) and Qualitative Habitat Evaluation Index (QHEI). Water samples were collected at all 22 sites during May 2024 to determine the presence of invasive carp eDNA. Because movement data collected during 2023 suggested late summer movements of invasive carps in the mainstem of the Eel River, ten mainstem sites in the Eel River were resampled for the presence of invasive carp eDNA during August 2024. In addition, the movement of invasive carps in the mainstem Eel River was tracked using a network of six antenna arrays installed from RM 36.5 to RM 75 that can detect Passive Integrated Transponder (PIT) tags and eight VR2TW and VR2Tx receivers installed from RM 1 to RM 75 that can detect acoustic tags. Active tracking of fish implanted with acoustic tags was conducted the entire length of the Eel River (RM 75 to RM 0).

Fish movement in the upper Wabash River, Tippecanoe River, Mississinewa River, and Salamonie River was tracked using a network of 12 VR2Tx receivers for detection of acoustic tags. Receivers in the Wabash River were installed upstream and downstream of the confluence of each of the four tributaries during May 2022. The remaining four receivers were installed in the mainstem channel of each tributary upstream of the confluence with the Wabash River. For this report, data were collected from May 2022 through 18 December 2024, but all 12 receivers remain operational.

Agency-Specific Accomplishments

Kentucky Department of Fish & Wildlife Resources (KDFWR)

During 2024, KDFWR maintained and offloaded 20+ tributary and mainstem receivers located in the upper Cannelton, McAlpine, and lower Markland pools. KDFWR also worked with other project partners to offload another 15+ receivers located in the furthest downstream pools

(Olmsted, Smithland and J.T. Myers) of the Ohio River. Field staff continued to assist the USFWS with tagging additional Silver Carp in the McAlpine and Cannelton pools to replace expired and/or harvested transmitters. KDFWR also established new stationary receiver sites (n = 7) in the upstream areas of the Kentucky (McAlpine Pool) and Salt (Cannelton Pool) rivers, which are located up to 60 miles above the existing sites near the mouths of each tributary. These new receivers will help determine if tagged carp have begun to occupy the upper reaches of tributaries that directly connect the Ohio River to valuable aquatic resources within Kentucky.

KDFWR continued to manage all data that project partners collected over the course of this reporting period. These efforts included the intensive processing of receiver data from 170+ sites in the Ohio River basin that was ultimately imported into the project's primary database (PostgreSQL), which consisted of more than 100M detection records through the end of 2024. KDFWR also maintained and updated multiple tables containing information on the project's tagged fish, stationary receiver sites, harvested tag reports and daily receiver histories. Additionally, KDFWR managed a second pgSQL database of environmental data that was collected from throughout the Ohio River Basin. Sources of this data included 60+ USGS gage stations and over a dozen temperature loggers that were deployed in conjunction with stationary receiver sites in the lower Cannelton Pool. Lastly, KDFWR compiled multiple data summaries and tables that were shared with all project partners and ultimately used to conduct most of the modelling/analysis efforts in this report.

Indiana Department of Natural Resources (INDNR)

INDNR subcontracted with ECI to complete work in the upper Wabash River evaluating movements of invasive carps in response to a dam removal. As part of this project, INDNR conducted a tagging event on the upper Wabash River during May 2024 and implanted 50 Silver Carp with acoustic transmitters. INDNR also regularly downloaded data from receivers in J.T. Myers and Newburgh pools including J.T. Myers, Newburgh, and Cannelton lock and dams. There data were sent to KDFWR for processing.

Ohio Division of Wildlife (ODOW)

ODOW maintained and offloaded data from mainstem and tributary receivers in the Markland (from Cincinnati to Meldahl L&D), Meldahl, and Greenup pools as well as those located at the Meldahl and Greenup L&Ds during 2024. All data were made available to KDFWR for processing.

West Virginia Division of Natural Resources (WVDNR)

WVDNR maintained and offloaded data from mainstem and tributary receivers in the R.C. Byrd Pool, including the portion of the Kanawha River within the pool. All data were sent to KDFWR for processing and reporting. To ensure that tagged fish were present in these areas and to determine the likelihood that translocated fish would move back upstream, WVDNR collaborated with USFWS-LGL FWCO to tag seven bigheaded carps in the old lock chambers of R.C. Byrd L&D and Raccoon Creek. Three of these fish were translocated downstream of R.C. Byrd L&D to examine dam passage by translocated fish.

U.S. Fish and Wildlife (USFWS)

During 2024, USFWS, Carterville FWCO (with assistance from state and federal partners, tagged a total of 502 Silver Carps in J.T. Myers (n = 100), Newburgh (n = 92), Cannelton (n = 200), and McAlpine (n = 110) pools following the methods above. The Carterville FWCO also used the data collected by state agencies and processed by KDFWR to parameterize multistate models to better understand pool-to-pool transition probabilities for Silver Carps. These data were also used to understand tributary use of Silver and Bighead Carps (see methods above for details). Additionally, the USFWS Ohio River Substation (Lower Great Lakes FWCO) continued maintenance of 27 VR2Tx receivers (16 at locks and dams and 11 within either mainstem or tributary locations) in R.C. Byrd, Racine, Belleville, and Willow Island pools. The substation took over the maintenance of this portion of the Ohio River Basin VR2 array from WVDNR during late fall 2022.

Illinois Department of Natural Resources, Southern Illinois University (ILDNR, SIU)

Southern Illinois University maintained 40 VR2 acoustic telemetry receivers throughout the Wabash River from the confluence with the Ohio River to 214 river miles upstream (near Terre Haute, Indiana) and within the White River, from its confluence with the Wabash River to 50 miles upstream. Receivers were retrieved and detections downloaded monthly when river conditions allowed. A new receiver stand was designed to improve retrieval of receivers in the rivers. Tagging of 70 invasive carps occurred in the Wabash River during November 2024.

Illinois Department of Natural Resources, Eastern Illinois University (ILDNR, EIU)

Eastern Illinois University conducted active tracking of acoustically tagged Silver Carps throughout the Wabash River during 2024 to identify patterns in fine-scale habitat use. Active tracking occurred monthly during daytime, with some additional nighttime active tracking taking place on select occasions to understand diurnal trends in fine-scale habitat use. Habitat characteristics were recorded at each fish's location, including macrohabitat type (river channel border, inside river bend, outside river bend) and microhabitat type (log jam, rip-rap, river run, thalweg). Additional microhabitat measurements, including substrate type, dissolved oxygen concentration, water velocity, water temperature, and water clarity were also measured at each fish's location. An analysis of fine-scale habitat use by silver carp showed that log jams were selected by this species and should be targeted for harvest removal.

Results and Discussion:

Ohio River

Acoustic Receiver Array: During 2024, 194 receivers were deployed from Olmsted Pool (including the lower Tennessee and Cumberland rivers and the Wabash River) to Willow Island L&D. Of these, 46 were deployed at L&Ds, 32 at mainstem sites, and 116 at tributary sites (Figure 1, Table 5).

Fish Tagging Efforts: As of July 2024, 2057 invasive carps (2011 Silver and 46 Bighead) from J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, Meldahl, and R. C. Byrd pools have been surgically implanted with acoustic transmitters (Table 6). Of the 2011 tagged carps, 45 Silver Carps have been harvested during the study (June 2013 – July 2024). One-hundred eighteen Silver Carps had tags that were expected to expire during 2024 (Table 6). To replace these tags and meet the needs of partner agencies, including expanding tagging in the lower Cannelton Pool to examine the effects of environmental conditions and commercial harvest on fish movements and residency, 502 Silver Carps were tagged in J.T. Myers (n = 100), Newburgh (n = 92), Cannelton (n = 200), and McAlpine (n = 110) pools. No Bighead Carps were tagged during 2024 due to a lack of availability.

Fish Detections: During 2024, there were 1521 tags deployed in invasive carps (1520 Silver Carps and 1 Bighead Carp) expected to be active in the Ohio River. Of these, 911 Silver Carps 543 (~60%) were detected. In addition, 58 invasive carps (54 Silver Carps and 4 Bighead Carps) whose tags were beyond their expected life were also detected on the Ohio River receiver array.

Fish Movement: Throughout the study area, the net movement (i.e., the difference between the most upstream and most downstream detections for an individual) ranged from 0.0 km to 634.9 km for Silver Carps and from 0.0 km to 92.9 km for Bighead Carps during August 2023 – July 2024. The longest net movement by a Silver Carp was completed by a male fish travelling from McAlpine Pool to the Lower Tennessee River during August – December 2023. In contrast, the longest net movement by a Bighead Carp occurred during October 2023 – May 2024 and was completed by a male fish that moved within Meldahl Pool. Long-distance movements are relatively rare for Silver Carp; ~85% of Silver Carp had a maximum distance travelled of < 30 km during August 2023 – July 2024. In contrast, 60% of Bighead Carp had a maximum distance travelled of < 30 km, however, given the small sample size (n = 5), these data should be interpreted cautiously.

Because there were relatively few detections of invasive carps in the pools upstream of Greenup L&D and below J.T. Myers L&D, further analysis of fish movement during June 2013 – July 2024 focused only on J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools. In these pools, net movements are typically shortest during December – March and peak during April – August regardless of species or pool (Figures 4 and 5). For Silver Carp, mean monthly net movements in Markland and Meldahl pools are typically longer than those in lower pools (Figure 5). In addition, a larger proportion of tagged Silver Carp had longer annual net movements in the upper pools examined (e.g., Markland and Meldahl pools) relative to the lower pools (e.g., J.T. Myers and Newburgh pools; Figure 6).

Dam Passage: Throughout the duration of this study (June 2013 – July 2024), there have been 1316 dam passage events (458 upstream and 858 downstream passages) (Figure 7). Dam passages were completed by 392 Silver Carps and 13 Bighead Carps. Of the upstream passages, 20 (4.4%) were completed by seven Bighead Carps. Four-hundred thirty-eight upstream passages (95.6%) were completed by 190 Silver Carps. Thirty downstream passages (3.5%) were completed by 11 Bighead Carps, whereas 828 (96.5%) were completed by 190 Silver Carps. Additionally, in only 324 of the 1316 dam passages (24.6%) was the fish detected within the lock chamber, suggesting a high prevalence of passages through the dam gates. Of these 324 dam passages, 250 were in the downstream direction, whereas 74 were in the upstream direction. Downstream passages through the lock chambers occurred at Greenup, McAlpine, Cannelton, Newburgh, J.T. Myers, Smithland, and Barkley (TNCR; Olmsted Pool) L&Ds during 2017-2024. Upstream passages through lock chambers occurred at R.C. Byrd, Greenup, Meldahl, Cannelton, Newburgh, J.T. Myers, Smithland and Barkley L&Ds. All dam passages through lock chambers occurred during 2017-2024.

The current arrangement of VR2 receivers around most L&D structures in the study area and their year-round deployment suggests a high probability of detecting invasive carps transitioning among pools through lock chambers. However, if fish pass through the dam gates they are unlikely to be detected in the vicinity of the dam, making it more challenging to understand pool-to-pool movements.

Tributary Use: Throughout the study period, ~77% of detected Silver Carps have been detected in tributaries of the Ohio River whereas, only ~55% of these fish have been detected in mainstem Ohio River habitats (Figure 8). In addition, when Silver Carps enter tributaries, they tend to spend more time (mean ± SE = 38.6 ± 1.1 days) there than in mainstem habitats (14.1 ± 0.6 days; Figure 9).

With the exception of J.T. Myers Pool, there is at least one tributary within each pool examined (J.T. Myers – Meldahl) that was visited by ≥25% of Silver Carps detected within that pool (Figure 10). In Newburgh Pool, only one tributary met this criterion, Little Pigeon Creek (54%). In Meldahl Pool, two tributaries, Ohio Brush Creek (81%) and the Scioto River (35%) exceeded this 25% threshold. McAlpine and Markland pools each contained three tributaries that were inhabited by ≥25% of tagged Silver Carps, Indian-Kentuck Creek (50%), the Little Kentucky River (39%) and the Kentucky River (71%) in McAlpine Pool and Big Bone Creek (27%), Laughery Creek (75%), and Hogan Creek (39%) in Markland Pool. Lastly, there were five tributaries in Cannelton Pool that were inhabited by ≥25% of tagged Silver Carps, Deer Creek (32%), Sinking Creek (35%), Oil Creek (33%), the Little Blue River (26%), and the Salt River (36%; Figure 10). These data suggest that not only do tributaries provide important habitat for Silver Carps, but some tributaries may provide more suitable habitat than others be preferred over others and should, therefore, be more closely monitored to determine if these areas can be targeted for control efforts.

Pool-to-Pool Transition Results: For Silver Carps, AIC_c indicated that for each model parameter (S, p, and ψ) only one model structure was supported (Tables 2-4). Based on this hierarchical model selection process (ΔAIC_c and W_i), the final model included a survival probability (S) that varied with month, a detection probability (p) that varied with the additive effects of pool and the number of receivers, and transition probabilities (ψ) that varied with the additive effects of pool and month. The AIC weights of 1 for each part of the hierarchical model selection process indicate little to no uncertainty in model selection.

The mean probability of survival (S) of Silver Carps varied with month such that survival was highest during cooler months (Dec – March) and lowest during April – June (Figure 11). Estimated mean survival probability was, however, high (0.96 – >0.99) for all months.

Estimated mean detection probabilities (p) for Silver Carp were affected by the additive effect of pool and the number of receivers and ranged from <0.01 to 1.00. The probability of detection increases following a sigmoidal curve such that there is typically a rapid increase in detection probability from 0 to ~10 receivers after which the rate of increase in detection probability slows (Figure 12). Interestingly, detection probabilities in the Greenup Pool and the Wabash River remain low, despite these areas having a similar number of receivers than some other pools with high detection probabilities (Figure 13). These differences likely reflect either a small number of tagged fish (Greenup Pool) or poor receiver recovery rates (Wabash River). In addition, although most pools show changes in detection probabilities that are highly correlated with the number of receivers recovered, Meldahl Pool shows a consistently high detection probability despite a reduction in the number of receivers recovered (Figure 13). This result suggests that there are potential efficiencies to be gained with strategic receiver placement throughout the Ohio River Basin.

Model estimates of mean transition probabilities (ψ) varied with the additive effect of pool and month and indicate that Silver Carps are most likely to move from one pool to another in April and October and are least likely to move among pools in August (Figure 14). Interestingly, transition probabilities from the Wabash River to the Smithland Pool and from the TNCR to the Olmsted Pool were consistently higher than those from the mainstem Ohio River. Although these results support the idea that these tributaries may act as source populations to the Ohio River Silver Carp population, it is important to note that movements from the Ohio River to these tributaries may be underestimated because there has been no tagging effort in either Smithland or Olmsted pools.

Within the mainstem Ohio River, transition probabilities among pools were typically low (< 0.2) with some exceptions (e.g., Greenup to Meldahl and J.T. Myers to Smithland during April and October) indicating that the probability of Silver Carps remaining within a pool was typically high (>0.8). Lastly, transition probabilities tended to higher in the downstream direction than in the upstream direction (Figure 14).

Wabash River

Fish Movement: The 2024 receivers detected between 36 and 80 unique tagged carp and had a range of 788 to 13,922 detections per receiver (Table 7). The most unique fish were detected in the upper river near Darwin, IL, and the fewest unique fish were detected at St. Francisville. The total number of detections was highly variable across our receivers, but SIU has not yet filtered these detections to remove possible dead fish or expelled tags from the record. The Wabash and White Rivers have presented unique challenges to passive telemetry. Under normal conditions water levels fluctuate rapidly, and the river carries a high sediment load, as well as other hazards such as downed trees. In 2024 the Wabash and White Rivers experienced a record drought, dropping water levels and making the river inaccessible for much of the summer. For these reasons, recovery of receivers has been limited to when ramps and river channels are deep enough for boat access, and even then, it is only possible if the receiver anchors have not been buried by sand and/or logs.

In 2025, SIU will continue to modify the deployment of receivers to improve the recovery rate. These modifications include tree set deployment, where the free end of the cable is attached to a tree on the bank. Tree set deployment began in 2024 and has thus far improved our ability to relocate and recover receivers, with all recovered receivers being a tree set, and one additional tree set receiver was successfully recovered in February 2025 (data not included in this report). For 2025 deployments, SIU is fabricating a new anchor design based on the recommendations of colleagues at Kentucky Fish and Wildlife, which has had success in similarly flashy and silty rivers. Finally, SIU is requesting permission from Indiana Department of Transportation to mount a bridge set receiver on the New Harmony Bridge in New Harmony, Indiana. Bridge sets are highly recoverable (Carlson et al., 2023), and this will provide consistent coverage of this section of the Wabash River.

The historical analysis of survival and detection of silver carp is in press in *Management of Biological Invasions*. Proportion detection probability of individuals was consistently > 0.8 among years. Survivorship analysis translated to annual mortality (mean + 95% confidence interval) for the tagged Silver Carp in the Wabash River being 0.03±0.02 across all years. Tagging is a robust method for tracking the survival of silver carp in the Wabash River and should be sensitive to harvest removal efforts.

Fine-Scale Habitat Selection (Eastern Illinois University):

Data (2021-2024) were analyzed for habitat (macro and micro) usage by sex (131 F, 294 M). Because of the uneven sex distribution, female and male carp were first analyzed separately. For each sex, the number of individuals at each category for macro and micro habitats were divided by the total number of individuals of that sex and converted into a percentage (Table 8). By calculating a percentage, data were standardized to allow for direct comparisons between sexes and bar plots were used to visualize distribution of habitat categories (Figure 15). Macro-habitat distributions by sex were very similar across categories, where outside bends are utilized most heavily, followed by channel border open, then inside bend, with the fewest detections in tributaries. However, it is important to note that access to tributaries by boat is dependent on water level. Slight differences were observed across micro-habitats. Males seem to utilize logjams at a higher rate than females (40% and 28%, respectively) who select run (29% F, 22% M) or thalweg (22% F, 16% M) habitats more frequently than males. Both male and female silver carp utilized riprap at the same rate (21%). Overall similarity between sexes is consistent with the results found by Prechtel et al (2018) for reaches of the Wabash River upstream of our sample sites.

Logistic regression was used to determine probability of use for macro and micro habitats depending on 2 hydrological parameters: temperature and percent maximum discharge using data for all fish detected by EIU during 2021-2023. For each model, macro and micro habitat categories were analyzed as a function of each hydrological category independently. Models were combined into probability of use plots including all macro (Figure 16) and micro (SIU Figure 17) categories for each hydrological parameter. For temperature, the outside bend macro-habitat maintained the highest probability of use regardless of temperature, while channel border open macro-habitat use increased at higher temperatures and inside bend macro-habitat decreased at higher temperatures. With micro-habitats, logjams had the highest probability of use at low temperatures, however all categories approached similar use as temperature increased. At the highest temperatures, riprap becomes the most used micro-habitat by a small margin. For discharge, outside bend macro-habitat maintained the highest probability of use regardless of discharge, while inside bend macro-habitat maintained the lowest usage regardless of discharge. At lower discharge, probability of use for channel border open macro-habitat was marginally higher than the inside bend but decreased with increasing discharge to the same probability of use as inside bend macro-habitat. With micro-habitat use, all categories are similar at low discharge with thalweg and riprap micro-habitat being slightly higher, however these two categories decline to near zero at high discharge. Conversely, thalweg and run micro-habitat use probability increases at higher discharge. At high discharge, logjams show the highest probability of use. It is important to recognize the co-occurrence of these hydrological variables when predicting habitat use of silver carp in that cooler, swifter water and warmer, slower water are associated with temporal variation in the Wabash River. The preference for logjams and run habitat at low temperatures and high discharge may allow for predictability of movement during the spring, while the similarity in probability of micro-habitats in higher temperatures and lower discharge may cause decreased predictability of movement during the late summer and early fall. It is also notable that in low water, characteristic of the Wabash in the late summer and early fall, logjam micro-habitats, while preferred in the spring, are frequently dried up on the banks where they cannot be used as habitat structures. During this time, the best predictor of habitat selection by silver carp is macro-habitat, as models indicate the highest probability of use for outside bend macro-habitat regardless of temperature or discharge. The implications of these data are useful in efforts to improve the harvest of invasive silver carp by targeting areas likely to be inhabited in higher densities.

Predictability in habitat selection by silver carp, and potential variability in behavior by sex, is important to understanding their dynamics as invaders of riverine ecosystems. Further, it enhances our ability to orchestrate more effective targeted removal efforts. Active tracking of fine-scale habitat movement has allowed for the collection of data to support such efforts. Future endeavors by EIU aim to further refine predictability by time of day through micro-tracking efforts. Through this research, we seek to provide managers throughout the Ohio River basin with the information needed to maximize harvest of these deleterious fish.

Invasive carp movement and distribution following dam removal

Results from the Eel River Basin in 2024 showed IBI scores ranged from "Very Poor" to "Good" in Eel River tributaries and "Fair" to "Excellent" in the mainstem Eel River. The initial eDNA samples that were collected during late spring 2024 detected Grass Carp DNA in 33% of replicates at RM 1 (Logansport) of the Eel River. Silver Carp DNA was detected in 33% of replicates at RM 36.3 (Below Stockdale Dam) of the Eel River (Table 9). Supplemental eDNA sampling, collected during late summer 2024, found Grass Carp DNA in 33% of replicates at RM 1 (Logansport) of the Eel River (Table 10). No Silver Carp or Bighead Carp DNA was detected in the supplemental sampling. In addition, Grass Carp were captured at River Mile (RM) 7.4 and RM 1 (Logansport) of the Eel River. No Silver Carp or Bighead Carp were captured during electrofishing surveys in 2024.

A total of 94 Silver Carp were detected by acoustic receivers installed in the Wabash River, Tippecanoe River, Eel River, and Mississinewa River. No Silver Carp have been detected near the confluence of Salamonie River and Wabash River or in the Salamonie River mainstem to date. Fish detected were tagged during eleven separate tagging events including multiple Silver Carp tagged in the Cumberland River, near Cheatham Dam (Table 11). There were also 17 Silver Carp detected in the Upper Wabash River that were tagged in the Lower Wabash River near the towns of Hutsonville, Illinois, Merom, Indiana, and New Harmony, Indiana. The fish tagged at these locations were detected at the most downstream receiver in the array in the Wabash River downstream of the confluence with the Tippecanoe River.

There were a total of 12,536 detections of Silver Carp during 2022, 14,878 detections during 2023, and 12,496 detections during 2024. A single receiver installed in the Wabash River upstream of the confluence with the Eel River accounted for 46%, 62%, and 36% of detections in in 2022, 2023, and 2024, respectively with the majority of those detections occurring during fall and winter each year (Figure 18). Silver Carp movement in the Upper Wabash River Basin was found to be seasonally dependent with fish undertaking longer distance upstream migrations during spring and, to a lesser extent, the summer and shorter distance downstream migrations during fall and winter (Figure 19). A total of 31 Silver Carp were detected during 2022, 54 during 2023, and 66 during 2024. The receivers in the Wabash River upstream and downstream of the confluence with the Tippecanoe River and within the mainstem of the Tippecanoe River had the highest number of Silver Carp detected of any receivers during 2023 and 2024. This was especially pronounced during spring (Figure 20). Seasonal changes in the number of Silver Carp detected on the receiver array were not as pronounced further up the Upper Wabash River, but the receiver in the Wabash River downstream of the confluence with the Mississinewa River showed a similar trend as the receivers in and around the Tippecanoe River where the number of

Silver Carp detected was highest during spring and decreased in each subsequent season during 2024.

Recommendations:

Despite the expansion of the receiver array in Cannelton Pool to better understand tributary vs mainstem habitat use, there are still gaps in the receiver array that, if filled, could further improve our understanding of invasive carp movement and habitat use. For instance, receiver coverage in Smithland and Olmsted pools is poor with only two mainstem receivers near in the upper portion of Olmsted Pool and eight receivers at the locks and dams at the lower and upper ends of Smithland pool. Increasing receiver coverage in these pools would not only improve our understanding of movement and habitat use of invasive carps in the Ohio River, but would also inform movement between the Ohio River and three other large rivers with established invasive carp populations, the Wabash River (Smithland Pool) and the Tennessee and Cumberland rivers (Olmsted Pool). Furthermore, deploying recievers at the downstream end of Olmsted Pool and in the open river between Olmsted Lock and Dam and the confluence of the Mississippi River would improve our understanding of movements between the Mississippi and Ohio rivers. Because all of these areas host large populations of invasive carps, understanding the movements of fish among these systems is critical to understanding source-sink dynamics and to effective management of these fishes. Specifically, understanding the movement of invasive carps between the Tennessee-Cumberland system and the Ohio River may elucidate movement patterns of invasive carps as they relate to deterrent technologies at Barkley Lock (e.g., do fish move away from the barrier at Barkley Lock and instead move upstream within the mainstem Ohio River?). In addition, broader spatial coverage in areas of low invasive carp density (i.e., upstream of Meldahl Pool) would help agencies understand the distribution of invasive carps in these areas and allocate removal efforts more efficiently. Accomplishing this may require the reallocation of some receivers in the upper pools to increase spatial coverage.

Although, current receiver deployments provide consistent year-round coverage of the lock chambers of all L&Ds between Smithland and Willow Island L&Ds, coverage near the gates of dams is lacking. Improving receiver coverage near dam gates could enhance our knowledge of pool-to-pool transitions (including the timing of these transitions as it relates to open-water conditions) as well as improve our ability to determine if L&D passages are primarily occurring through the lock chambers or through the dam gates. However, site selection near dam gates requires careful consideration because deploying stationary receivers in these areas is logistically challenging and raises concerns for the safety of agency personnel that would be tasked with downloading and maintaining the receivers.

There are currently 56 receivers deployed in the Wabash River. However, low waters and siltation has resulted in difficulties retrieving these receivers, especially in summer 2024. These difficulties retrieving receivers mean that less information is being gathered in that system. Improving retrieval success is critical to understanding invasive carp movement within the Wabash River as well as among the Wabash and Ohio rivers. SIU is currently working to retrieve additional receivers and test different receiver deployments in the hopes of improving retrieval success.

In addition to adding receivers in specific areas to improve coverage, understanding the true coverage provided by those receivers currently deployed is critical to our understanding of fish movements and habitat use. The current combination of VR2W receivers and V16 transmitters used for invasive carp telemetry in the Ohio River ostensibly provides a detection range of 800 – 1200 m. Ambient conditions (e.g., turbidity, flow, receiver orientation) can, however, drastically affect detection ranges. It is, therefore, recommended that receivers be range-tested during a variety of conditions to determine reasonable expectations for the detection range of receivers in the Ohio River system.

Lastly, data management will continue to be vital as the telemetry program adds to the existing data set. Increases in the number of invasive carp detections are anticipated, especially within the lower pools of the Ohio River where the array and tagging efforts were expanded during 2021. Due to the expected increase in detections, front-end data management and data processing capability will become increasingly important to ensure that data are available for analysis in a timely manner. Furthermore, to accommodate the likely increase in time necessary to process and analyze these larger quantities of data, it is recommended that, as in 2022, each agency perform a download of all receivers in their areas of management and transfer the downloaded data to KDFWR by July 31 of each year. This will allow ample time for data processing, analysis, and reporting, and increase time for discussion of the results and potential improvements to analyses prior to reporting in March of the following year.

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Tables and Figures

Table 1. The ID number, pool, and available data for US Geological Survey gage stations used in the pool-to-pool multistate model.

Gage ID	Pool	Gage Height	Temperature
03399800	Olmsted	X	
03611000	Olmsted	X	
03612600	Olmsted	X	X
03381700	Smithland	X	
03377500	Wabash	X	
03378500	Wabash	X	X
03304300	J.T. Myers	X	
03322000	J.T. Myers	X	
03322190	J.T. Myers	X	
03322420	J.T. Myers	X	
03303280	Newburgh	X	X
03294500	Cannelton	X	
03294600	Cannelton	X	
03292494	McAlpine	X	X
03293551	McAlpine	X	
03255000	Markland	X	
03217200	Meldahl	X	
03206000	Greenup	X	
03216000	Greenup	X	
03201500	R.C. Byrd	X	

Table 2. Model selection results for survival probability (*S*) of the multi-state with live recaptures model for Silver Carp pool-to-pool movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures that converged for survival probability. The covariates affecting estimates of the survival probability are shown in parentheses and include temperature (temp), month, season, and pool. The "." notation indicates an invariant survival probability. The model structures for detection (*p*) and transition (ψ) probabilities were held constant and included only a pool effect for both parameters.

Model	npar	AIC_c	ΔAIC_c	W_i
$S(month)p(pool)\psi(pool)$	46	166678.8	0	1
$S(temp)p(pool)\psi(pool)$	36	166719.3	44.6	0
$S(.)p(pool)\psi(pool)$	35	166745.0	70.2	0
$S(season)p(pool)\psi(pool)$	38	166767.2	92.4	0

Table 3. Model selection results for detection probability (*p*) of the multi-state with live recaptures model for Silver Carp pool-to-pool movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures for detection probability. The covariates affecting estimates of the detection probability are shown in parentheses and include the number of receivers (num_rec), the number of receivers per river mile (rprm), median standardized gage height (height), month, season, and pool. The "." notation indicates an invariant detection probability. The model structures for survival (*S*) and transition (ψ) probabilities were held constant and included only a month effect for *S* (the best supported model structure) and a pool effect for ψ.

Model	npar	AIC_c	ΔAIC_c	W_i
$S(month)p(pool + num\_rec)\psi(pool)$	47	162221.6	0	1
$S(month)p(rprm)\psi(pool)$	36	164688.9	2467.3	0
$S(month)p(pool*month)\psi(pool)$	178	165214.4	2992.8	0
$S(month)p(pool*season)\psi(pool)$	82	165529.3	3307.7	0
$S(month)p(pool + month)\psi(pool)$	57	165560.6	3338.9	0
$S(month)p(pool + season)\psi(pool)$	49	165977.2	3755.6	0
$S(month)p(num\_rec)\psi(pool)$	36	166388.8	4167.2	0
$S(month)p(pool)\psi(pool)$	46	166674.8	4453.2	0
$S(month)p(pool + height)\psi(pool)$	47	166676.8	4455.2	0
$S(month)p(month)\psi(pool)$	46	171886.7	9665.1	0
$S(month)p(season)\psi(pool)$	38	172225.2	10003.6	0
$S(month)p(.)\psi(pool)$	35	172864.2	10642.6	0
$S(month)p(height)\psi(pool)$	36	172866.3	10644.6	0

Table 4. Model selection results for transition probabilities (ψ) of the multi-state with live recaptures model for Silver Carp pool-to-pool movements. The table shows the model structure, number of parameters in the model (npar), AIC_c, ΔAIC_c, and the AIC weight (W_i) for all model structures that converged for transition probabilities. The covariates affecting estimates of the transition probabilities are shown in parentheses and include median standardized gage height (height), month, the number of open river days per month (ord), and pool. The model structures for survival (*S*) and detection (*p*) probabilities were held constant and included only a month effect for *S* and the additive effect of pool and number of receivers (num_rec) for *p*.

Model	**npar**	**AIC_c**	**ΔAIC_c**	**W_i**
$S(month)p(pool + num\_rec)\psi(pool + month)$	59	162156.8	0	1
$S(month)p(pool + num\_rec)\psi(pool + height)$	48	162188.8	32.0	0
$S(month)p(pool + num\_rec)\psi(pool + ord)$	48	162216.2	59.4	0
$S(temp)p(pool + rprm)\psi(pool)$	47	162221.6	64.8	0

Table 5. Number and distribution of VR2 receivers in the Ohio River and three major tributaries, the Wabash River and the Tennessee/Cumberland rivers (TNCR), during 2024. One-hundred ninety-four receivers were deployed from Olmsted pool, downstream of the Smithland lock and dam, to Willow Island lock and dam.

Ohio River Pool/River	Pool/River Length (km)	Lock and Dam Receivers (N)	Mainstem Receivers (N)	Tributary Receivers (N)	Total Receivers (N)
Olmsted	73.9	3	2	0	5
TNCR	222.2	5	0	7	12
Smithland	116.7	4	0	0	4
Wabash	344.5	0	0	20	20
J.T. Myers	112.5	4	1	15	20
Newburgh	89.2	4	0	8	12
Cannelton	183.4	1	9	28	38
McAlpine	121.2	3	1	7	11
Markland	153.4	3	2	8	13
Meldahl	153.3	3	7	6	16
Greenup	99.5	3	3	4	10
R.C. Byrd	67.1	4	5	9	18
Racine	54.1	5	0	2	7
Belleville	67.9	3	2	2	7
Willow Island	56.8	1	0	0	1
Total	NA	46	32	116	194

Table 6. The number of Silver and Bighead Carps tagged with acoustic transmitters by year and pool during June 2013 – December 2024. Numbers in parenthesis are fish with tags that have been reported as harvested before expected tag expiration and, therefore, are no longer active. Tags deployed for > 4 years are expected to be expired (inactive). Also included are species composition calculations for the tags expected to be active in each pool and the mean total length (mm) of all tagged fish by pool.

Year(s)	Status	Species	Ohio River Pool								Total
			J.T. Myers	Newburgh	Cannelton	McAlpine	Markland	Meldahl	Greenup	R.C. Byrd	
2013-2018	Inactive	SVCP	-	-	182 (10)	226 (5)	49 (1)	34	-	-	491
		BHCP	-	-	4	6	11	21	-	3	45
2019	Active	SVCP	-	-	-	30	-	-	-	-	30
		BHCP	-	-	-	1	-	-	-	-	1
2020	Active	SVCP	-	-	-	100	18	-	-	-	118
2021	Active	SVCP	226 (1)	230	92 (5)	97 (2)	3	-	-	-	648
2022	Active	SVCP	(2)	(1)	109 (5)	-	29	-	-	-	138
2023	Active	SVCP	-	-	(7)	-	54(1)	30	-	-	84
2024	Active	SVCP	100	92 (1)	200 (4)	110 (2)	-	(1)	-	-	502
2019-2024	Active	SVCP	326	322	401	337	104	30	-	-	1,520
		BHCP	-	-	-	1	-	-	-	-	1
2013-2018 (Including harvested)	Inactive	SVCP	-	-	182	226	49	34	-	-	491
		BHCP	-	-	4	6	11	21	-	3	45
		Overall	-	-	186	232	60	55	-	3	533
% Species Composition	Active	SVCP	21.4	21.2	26.4	22.2	6.8	2.0	0	0	100
		BHCP	-	-	-	0.1	-	-	-	-	-
Mean TL (mm)	Combined	SVCP	706.7	714.4	787.7	817.8	893.8	949.0	-	-	811.6
		BHCP	-	-	1139.8	1146.3	1175.1	1153.6	-	1210	1165.0

Table 7. Summary of detections from the seven successfully recovered receivers in 2024.

Receiver	Unique fish detected	Total number of unfiltered detections	Location
VR2Tx-486769	41	12069	Hutsonville
VR2Tx-486794	75	13922	Terre Haute
VR2Tx-490845	62	12181	Fay’s Landing
VR2Tx-490849	80	12301	Darwin
VR2Tx-125867	43	2713	Mt. Carmel
VR2Tx-138898	46	12918	Mt. Carmel
VR2Tx-138912	36	788	St. Francisville

Table 8. Percentages of fish detections by sex for macro-habitat, micro-habitat, and their respective categories.

Variable	Category	Males	Females
Macro-habitat	Channel Border Open	30%	31%
	Inside Bend	22%	22%
	Outside Bend	43%	40%
	Tributary	5%	7%
Micro-habitat	Run	22%	29%
	Logjam	40%	28%
	Thalweg	16%	22%
	Riprap	21%	21%

Table 9. Percent of replicates that were above detection limits for Bighead Carp, Silver Carp, and Grass Carp DNA at 24 sampled sites in the Eel River and the Wabash River in the spring 2024 sampling.

					Percent of Replicates that Detected DNA		
Site Type	Site Name	River Mile	Latitude	Longitude	Bighead Carp	Silver Carp	Grass Carp
Mainstem Eel River	Columbia City	RM 75	41.118	-85.499	0	0	0
	Collamer	RM 63.7	41.074	-85.664	0	0	0
	Liberty Mills	RM 57.3	41.038	-85.739	0	0	0
	North Manchester	RM 50.9	40.995	-85.781	0	0	0
	Above Stockdale Dam	RM 36.8	40.914	-85.941	0	0	0
	Below Stockdale Dam	RM 36.3	40.912	-85.951	0	33	0
	Mexico	RM 18.7	40.818	-86.108	0	0	0
	Hoover	RM 12.3	40.797	-86.198	0	0	0
	Adamsboro	RM 7.4	40.783	-86.264	0	0	0
	Logansport	RM 1	40.759	-86.364	0	0	33
Tributary of the Eel River	Geller Ditch		41.207	-85.429	0	0	0
	Johnson Ditch		41.245	-85.386	0	0	0
	Shoaff Ditch		41.206	-85.217	0	0	0
	Thorn Creek		41.162	-85.296	0	0	0
	Blue River		41.207	-85.235	0	0	0
	Beargrass Creek Upper		40.898	-85.753	0	0	0
	Beargrass Creek Lower		40.878	-85.966	0	0	0
	Squirrel Creek Upper		40.965	-85.94	0	0	0
	Squirrel Creek Lower		40.917	-85.939	0	0	0
	Pawpaw Creek Upper		40.932	-85.779	0	0	0
	Pawpaw Creek Lower		40.943	-85.89	0	0	0
	Weesau Creek		40.867	-86.086	0	0	0
Mainstem Wabash River	Downstream of Eel River	RM 352	40.747	-86.411	0	0	0
	Upstream of Eel River	RM 358	40.75	-86.301	0	0	0

Table 10. Percent of replicates that were above detection limits for Bighead Carp, Silver Carp, and Grass Carp DNA at 11 sampled sites in the Eel River and the Wabash River in the late summer 2024 sampling.

					Percent of Replicates that Detected DNA		
Site Type	Site Name	River Mile	Latitude	Longitude	Bighead Carp	Silver Carp	Grass Carp
Mainstem Eel River	Columbia City	RM 75	41.118	-85.499	0	0	0
	Collamer	RM 63.7	41.074	-85.664	0	0	0
	Liberty Mills	RM 57.3	41.038	-85.739	0	0	0
	North Manchester	RM 50.9	40.995	-85.781	0	0	0
	Above Stockdale Dam	RM 36.8	40.914	-85.941	0	0	0
	Below Stockdale Dam	RM 36.3	40.912	-85.951	0	0	0
	Mexico	RM 18.7	40.818	-86.108	0	0	0
	Hoover	RM 12.3	40.797	-86.198	0	0	0
	Adamsboro	RM 7.4	40.783	-86.264	0	0	0
	Logansport	RM 1	40.759	-86.364	0	0	33
Wabash River	Upstream of Eel River	RM 358	40.75	-86.301	100	100	0

Table 11. River name, site name, date of tagging, and number of individuals detected in the Upper Wabash River Basin network of receivers from the identified tagging event.

River Fish was Tagged In	Site Name	Date of Tagging	Number of Individuals Detected from Tagging Event
Wabash River	Lafayette	4/1/2011	2
Cumberland River	Cheatham Dam	3/2/2021	2
Wabash River	Above Lafayette	9/14/2021 and 9/15 2021	7
Wabash River	Hutsonville	11/1/2021 and 4/18/2022	8
Wabash River	Omer Cole Ramp	8/2/2022 and 8/3/2022	23
Wabash River	Lafayette	3/29/2023 and 3/30 2023	34
Eel River	Stockdale Dam	7/5/2023	1
Wabash River	Merom	11/1/2023	6
Wabash River	New Harmony	11/3/2023	3
Wabash River	Lafayette	5/8/2024	8

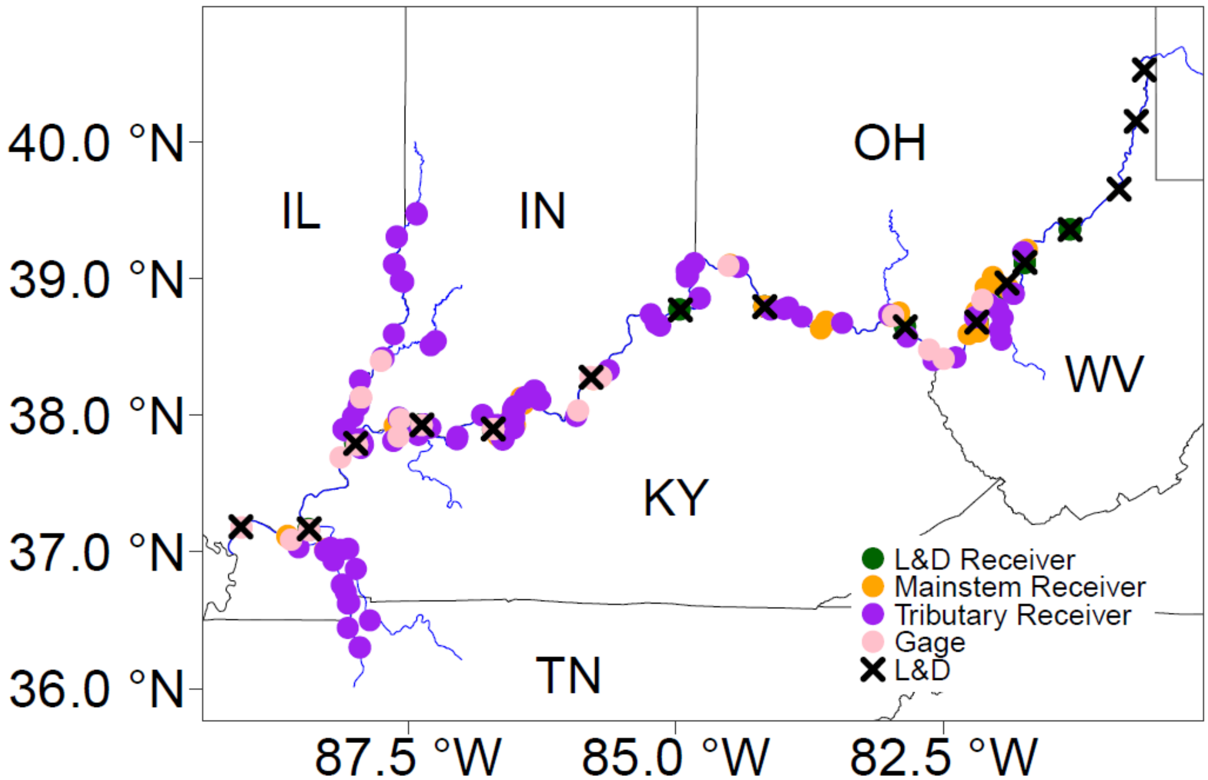

Figure 1. Locations of mainstem Ohio River Lock and Dam structures (L&D; black crosses), USGS gage stations (pink circles), and acoustic receivers deployed at L&D structures (green circles), in the mainstem (orange circles), and tributaries (purple circles) of the Ohio River during 2024. Map shows the Ohio River and some of its major tributaries (blue) from the confluence of the Ohio and Mississippi rivers in the west to the Pennsylvania border in the east. Receivers were deployed from Olmsted Pool, downstream of the Smithland L&D, to the Willow Island L&D. From west to east, the L&Ds are Olmsted, Smithland, J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, Meldahl, Greenup, R.C. Byrd, Racine, Belleville, Willow Island, Hannibal, Pike Island, and New Cumberland. Ohio River pools are named for the downstream L&D (e.g., Olmsted Pool begins at Olmsted L&D and ends at Smithland L&D).

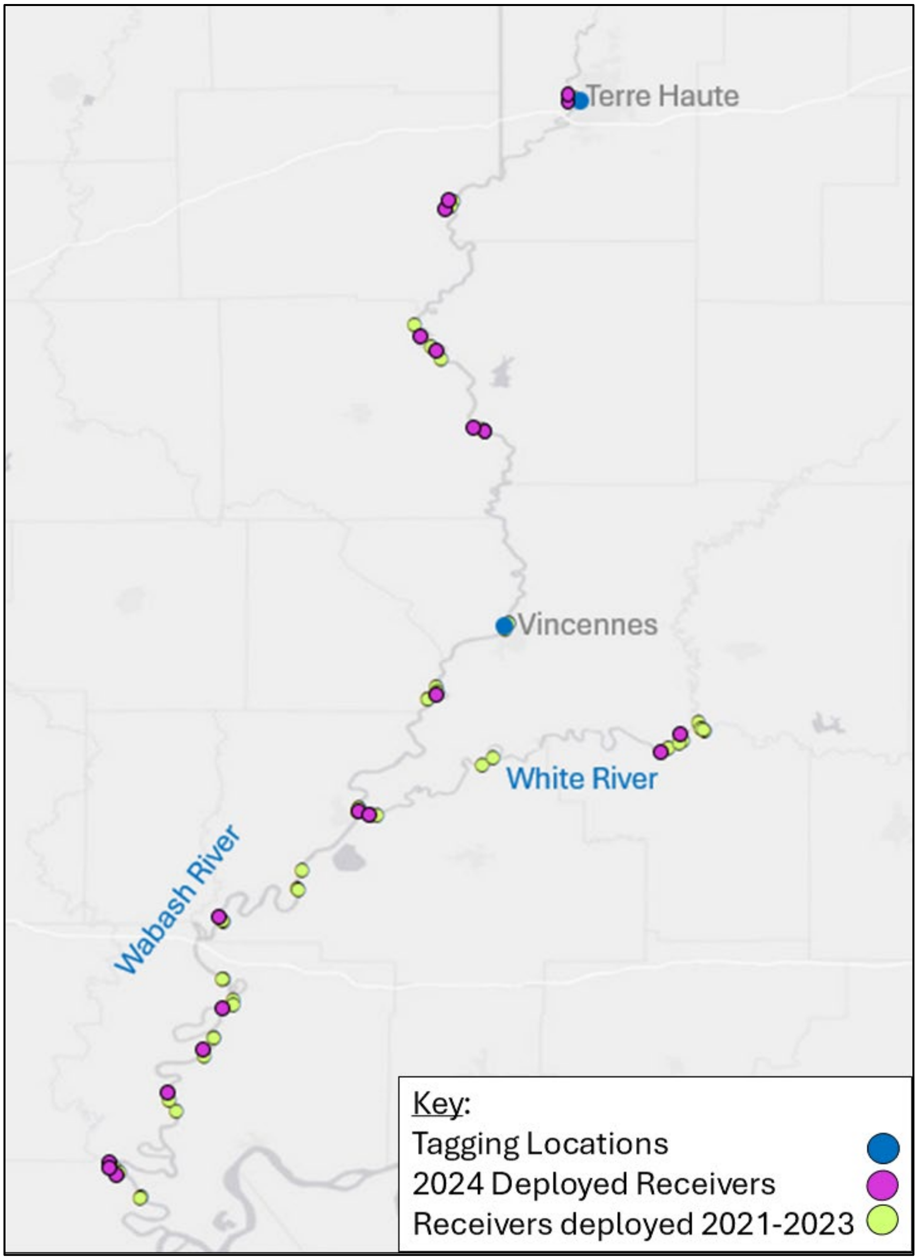

Figure 2. Map of tagging locations (blue), receivers newly deployed in 2024 (pink) and existing receivers (yellow).

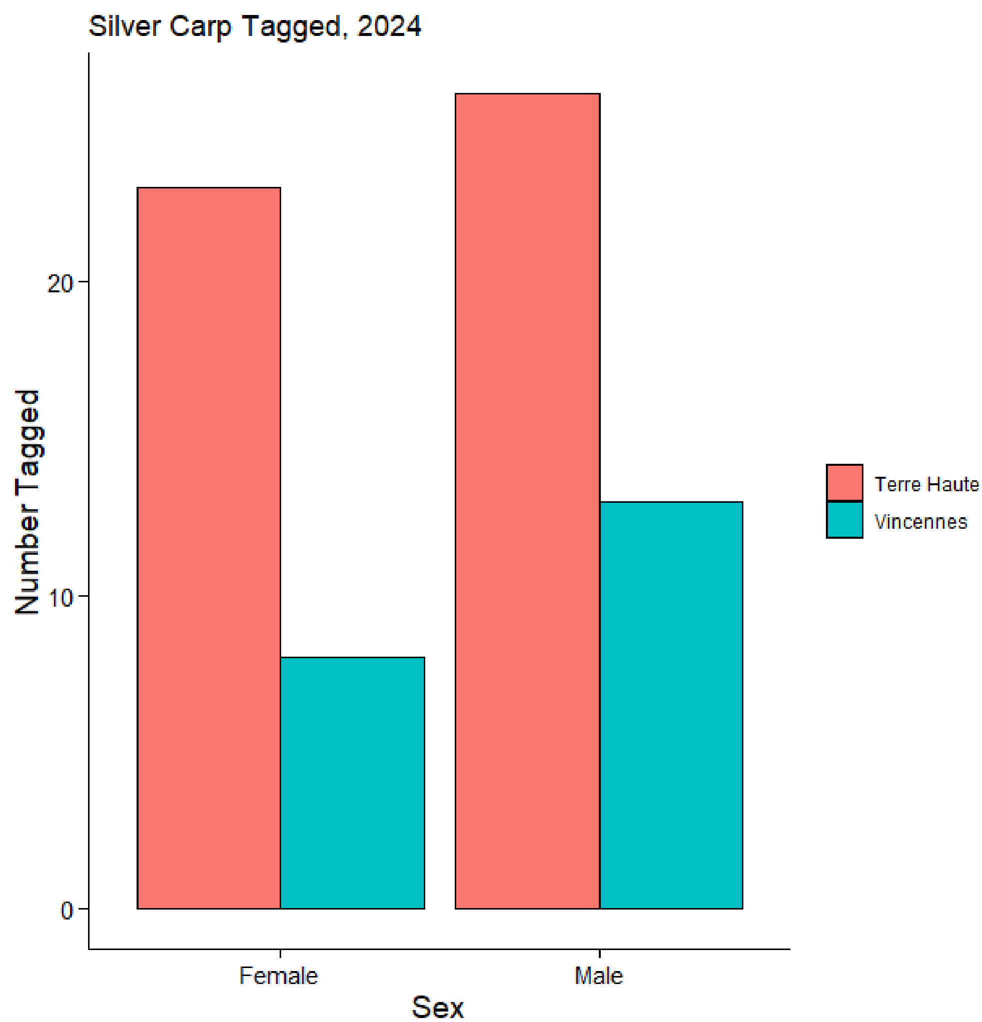

Figure 3. Sex and location breakdown of the 70 silver carp tagged in 2024.

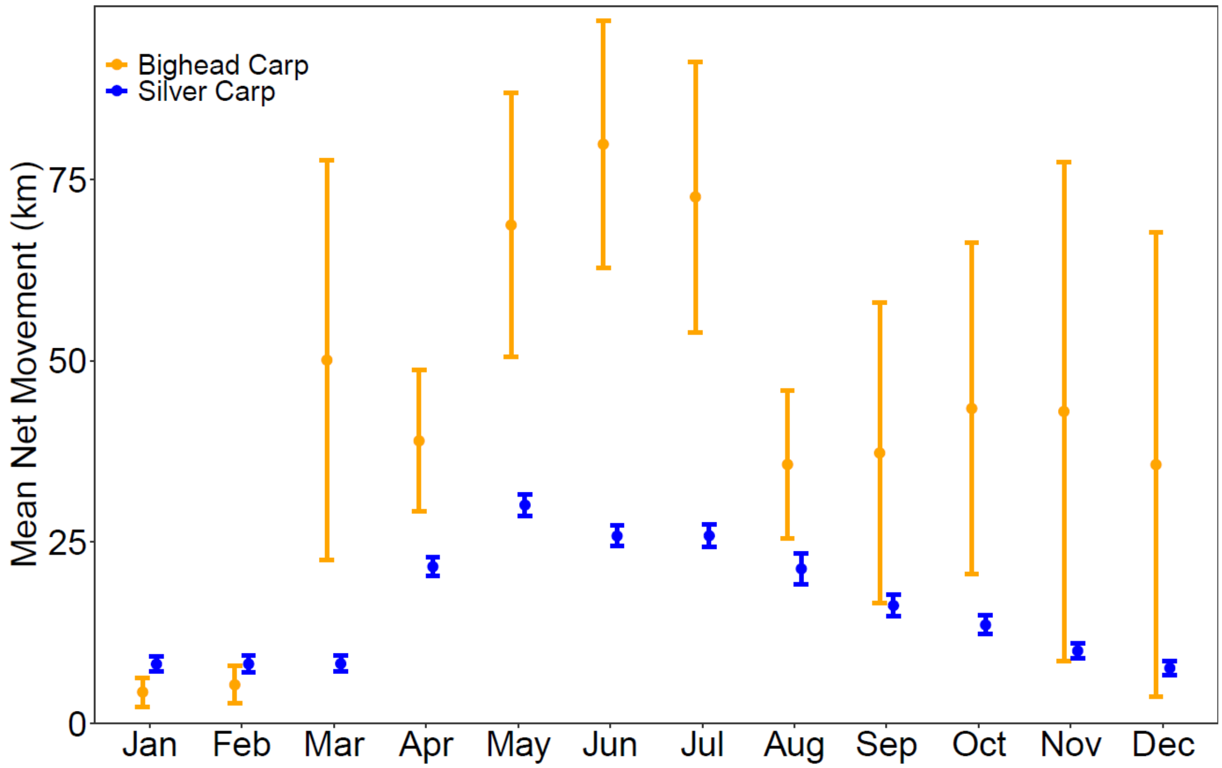

Figure 4. The mean monthly net movements (river kilometers) between the most upstream and downstream detections for tagged Silver Carp (blue) and Bighead Carp (orange) in J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools during June 2013 – July 2024. Error bars represent standard error. Only tagged carp detected ≥ 2 times during a month were included in the distance calculations.

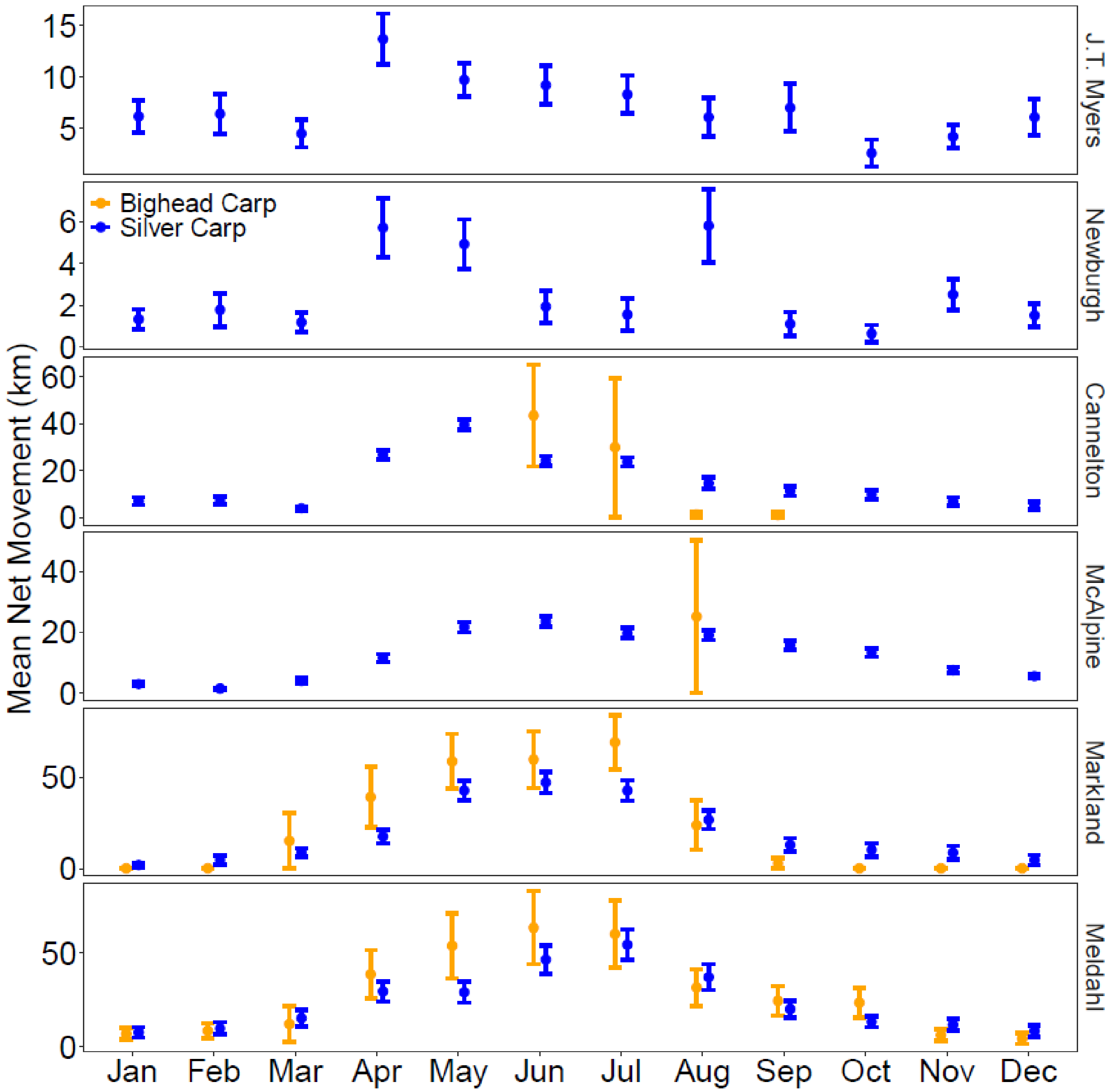

Figure 5. The mean monthly net movements (river kilometers) between the most upstream and downstream detections for tagged Silver Carp (blue) and Bighead Carp (orange) by pool in the six most active pools of the telemetry project (J.T. Myers, Newburgh, Cannelton, McAlpine, Markland, and Meldahl pools) during June 2013 – July 2024. Error bars represent standard error. Only tagged carp detected ≥ 2 times within a single pool each month were included in the distance calculations.

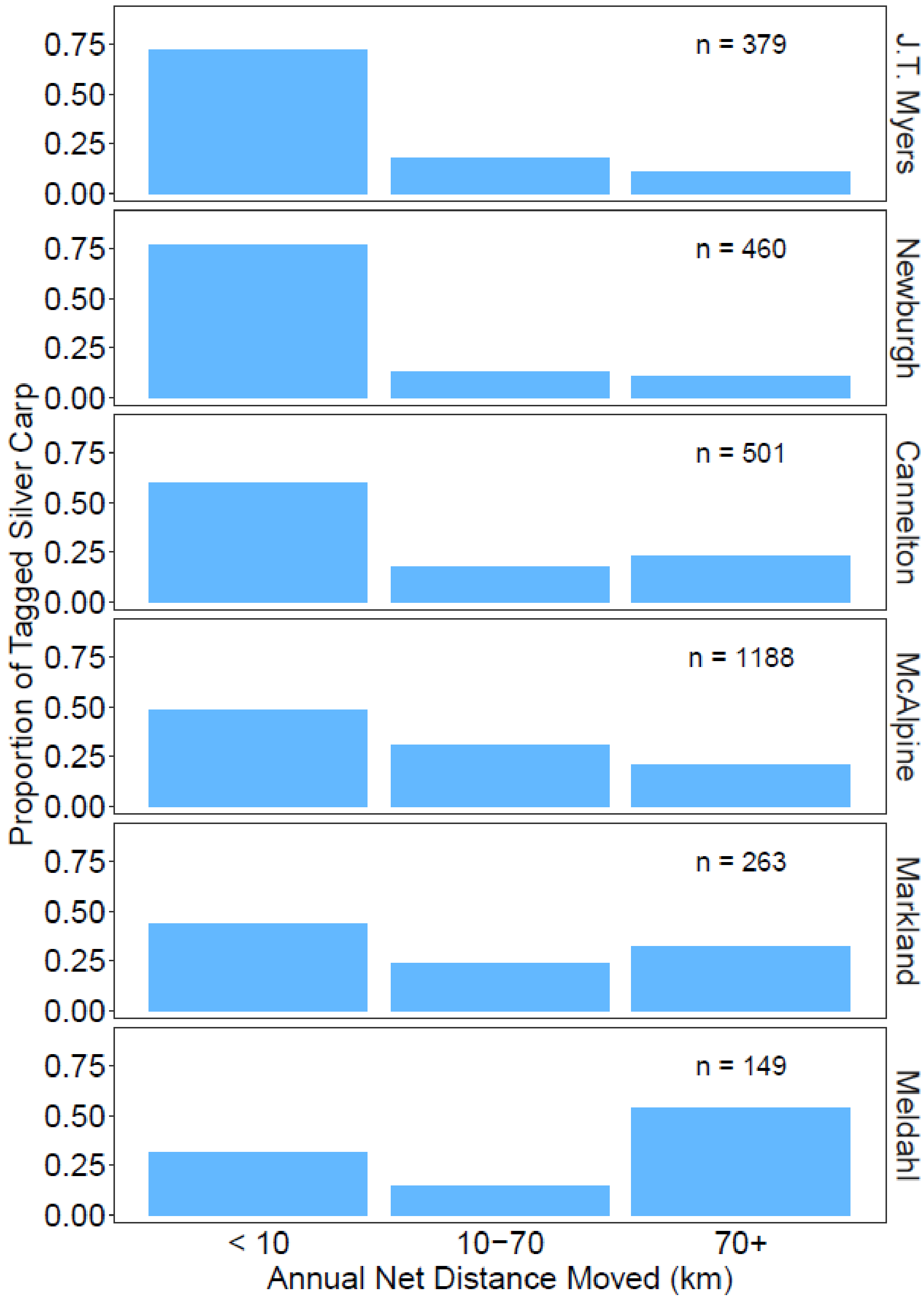

Figure 6. The proportion of tagged Silver Carp with annual net movements of < 10, 10-70, or 70+ km for each pool from J.T. Myers to Meldahl pools (top to bottom) during June 2013 – July 2024. The number of individuals included in this summarization is included in the top-right corner of each panel.

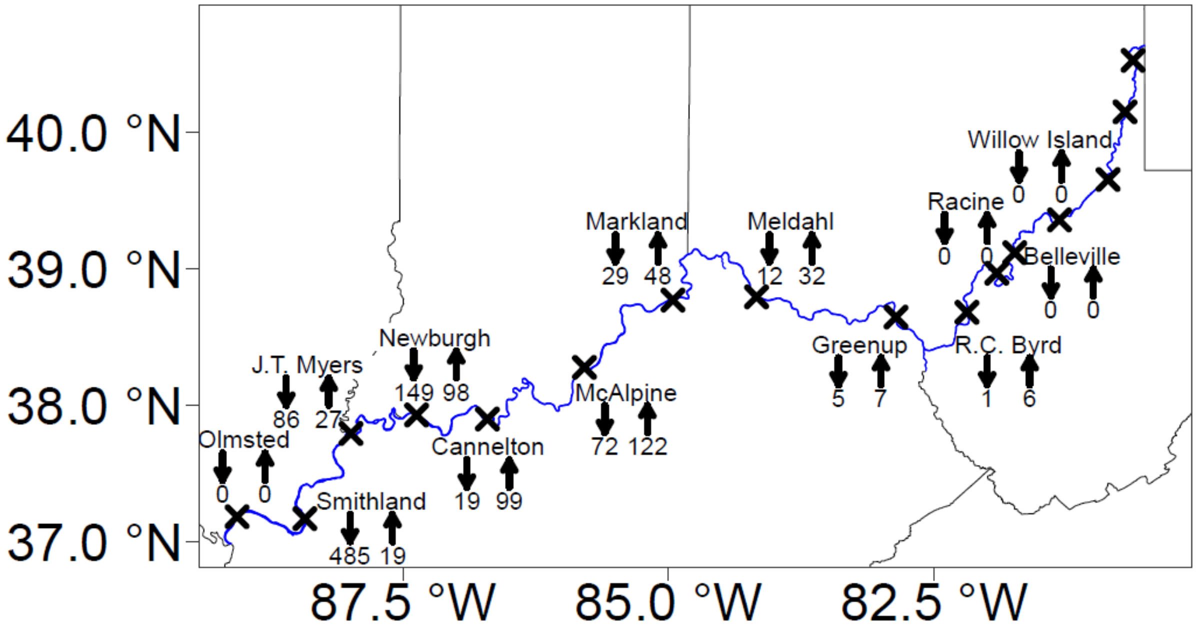

Figure 7. Total number of downstream (↓) and upstream (↑) lock and dam (L&D) passages by invasive carps during June 2013 – July 2024. Map shows passages from Olmsted L&D (river mile 964.4) near the confluence of the Ohio and Mississippi rivers to Willow Island L&D (river mile 161.7) which is the most upstream location at which acoustic receivers were deployed.

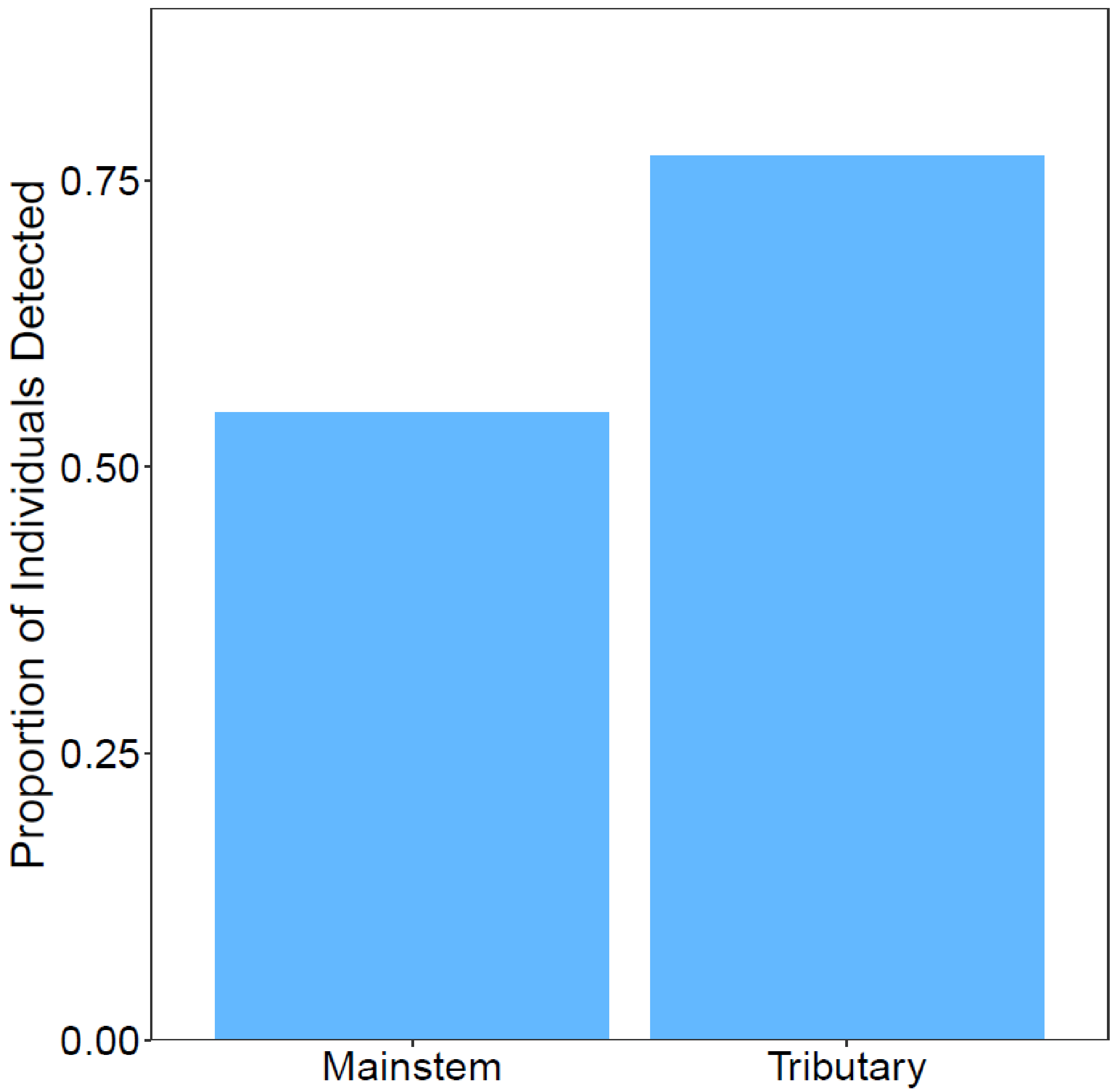

Figure 8. The proportion of individual Silver Carp detected in mainstem and tributary habitats during June 2013 – July 2024.

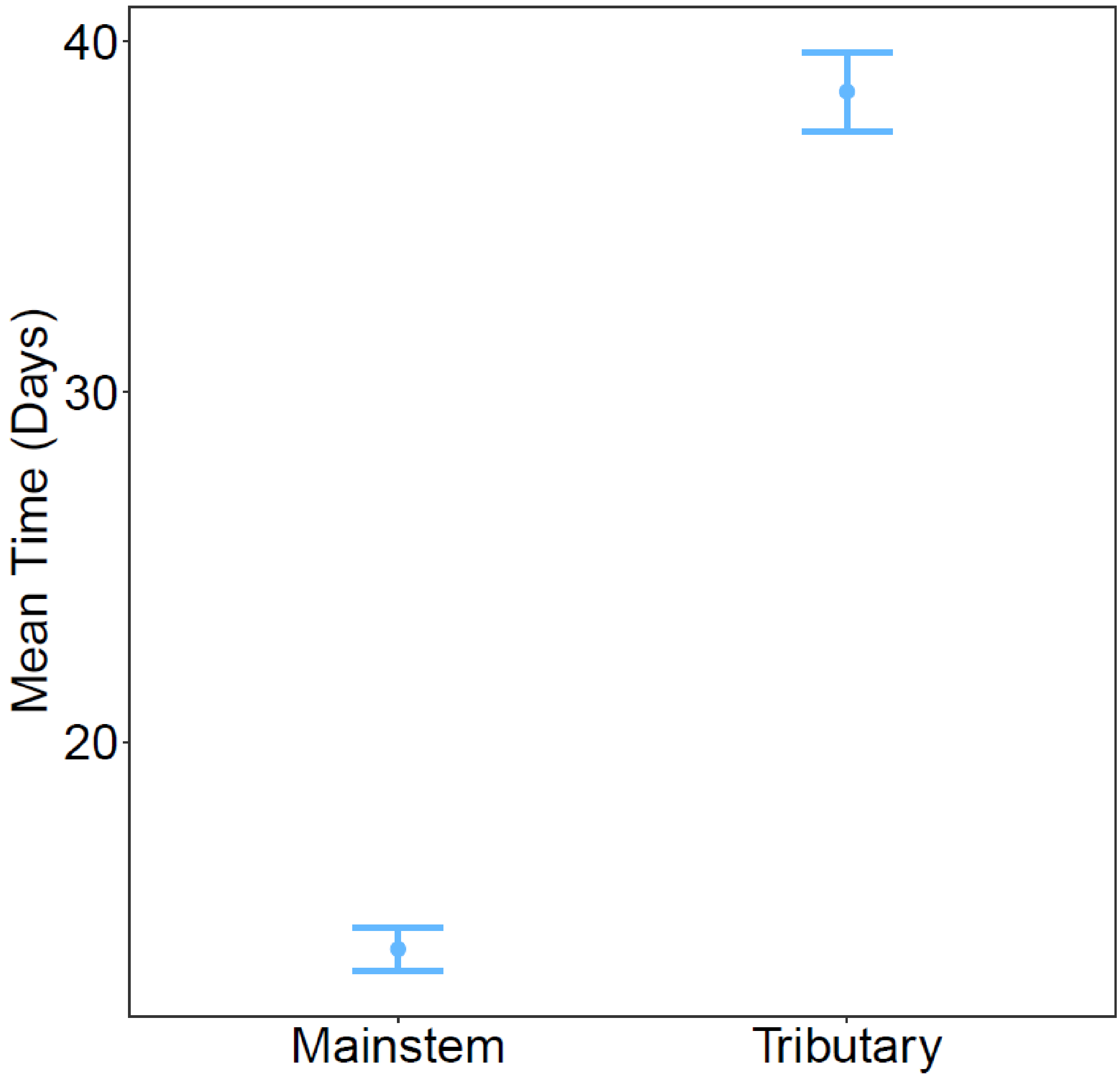

Figure 9. The mean time (days) spent in mainstem or tributary habitat for Silver Carps during June 2013 – July 2024. The number of days represents the time from the first detection of an individual in either the mainstem of the Ohio River or one of its tributaries to the first detection outside of that habitat.

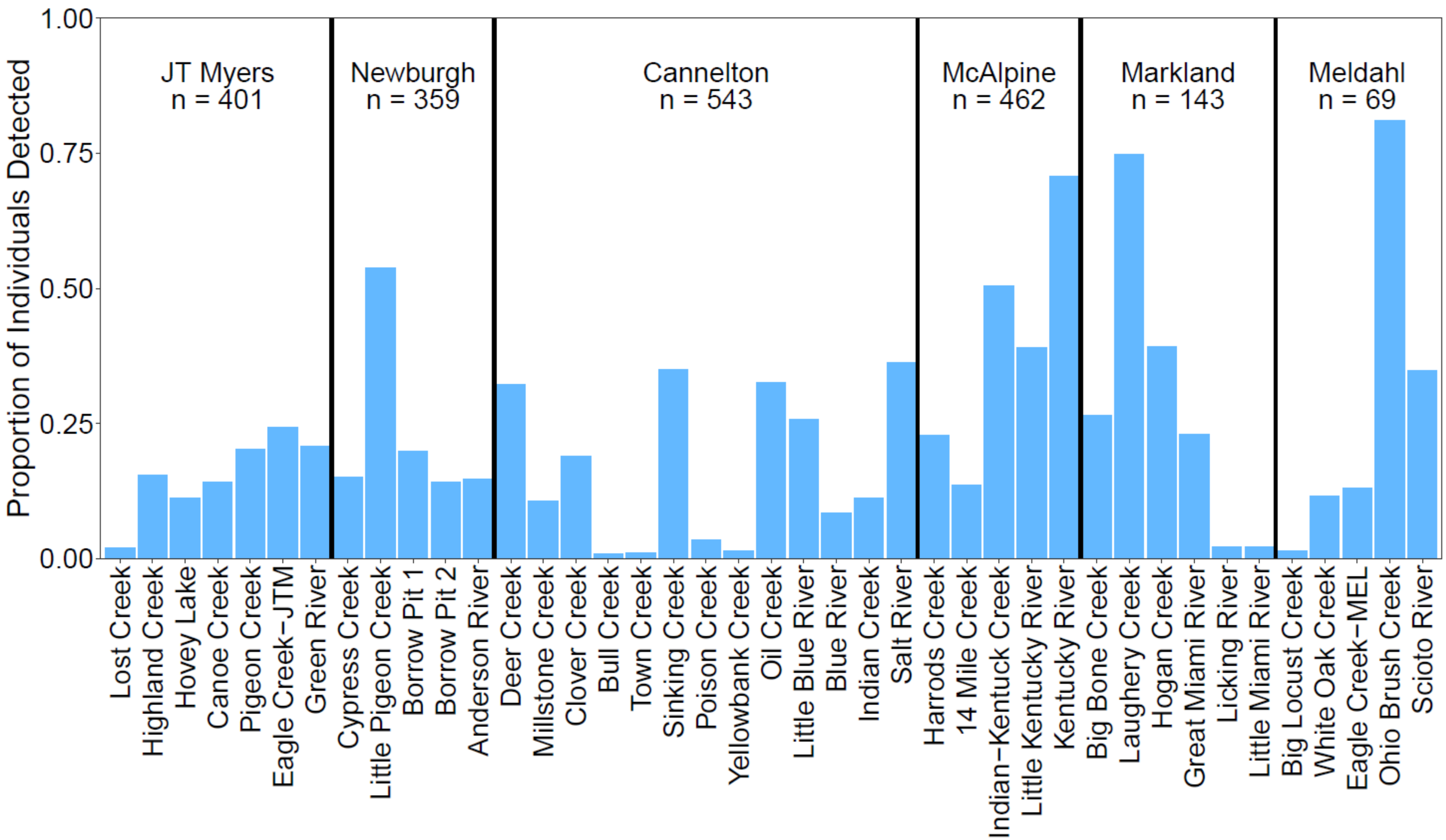

Figure 10. The proportion of individual Silver Carp in each pool that were detected in tributaries of those pools during June 2013 – July 2024. Numbers represent individual fish detected within that pool and the vertical lines are used to separate pools from most downstream to most upstream.

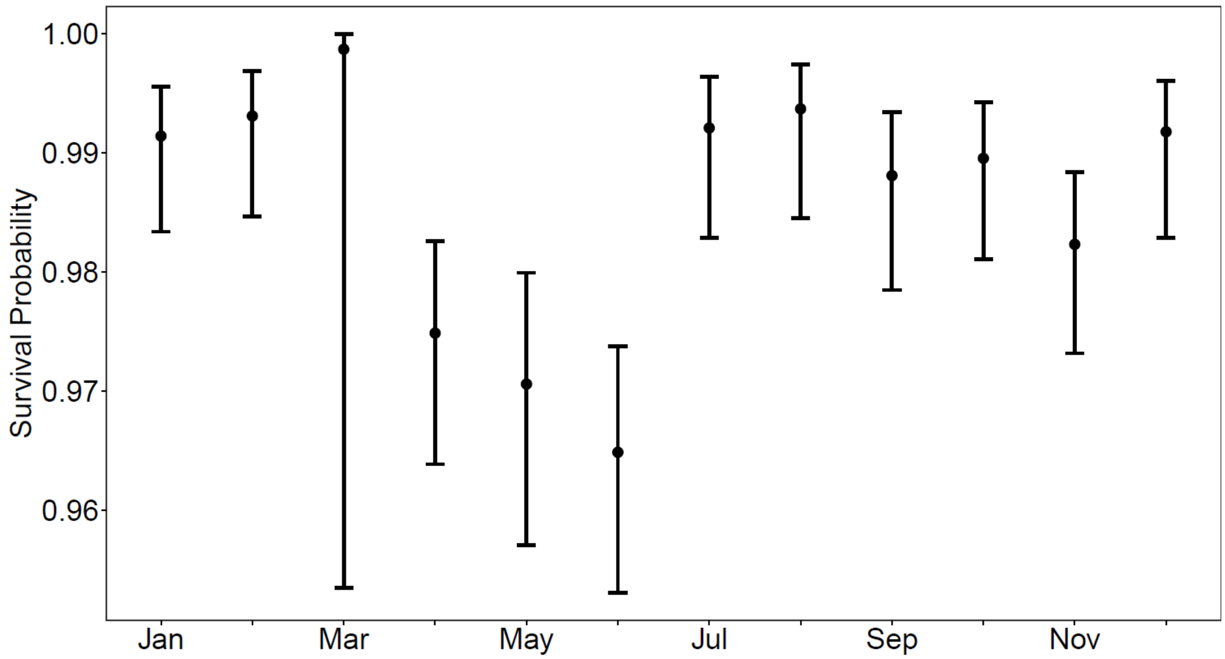

Figure 11. The effect of month on the probability of survival (S) of Silver Carps during January 2014 – July 2024. The plot shows the mean probability of survival ± 95% confidence intervals for each month.

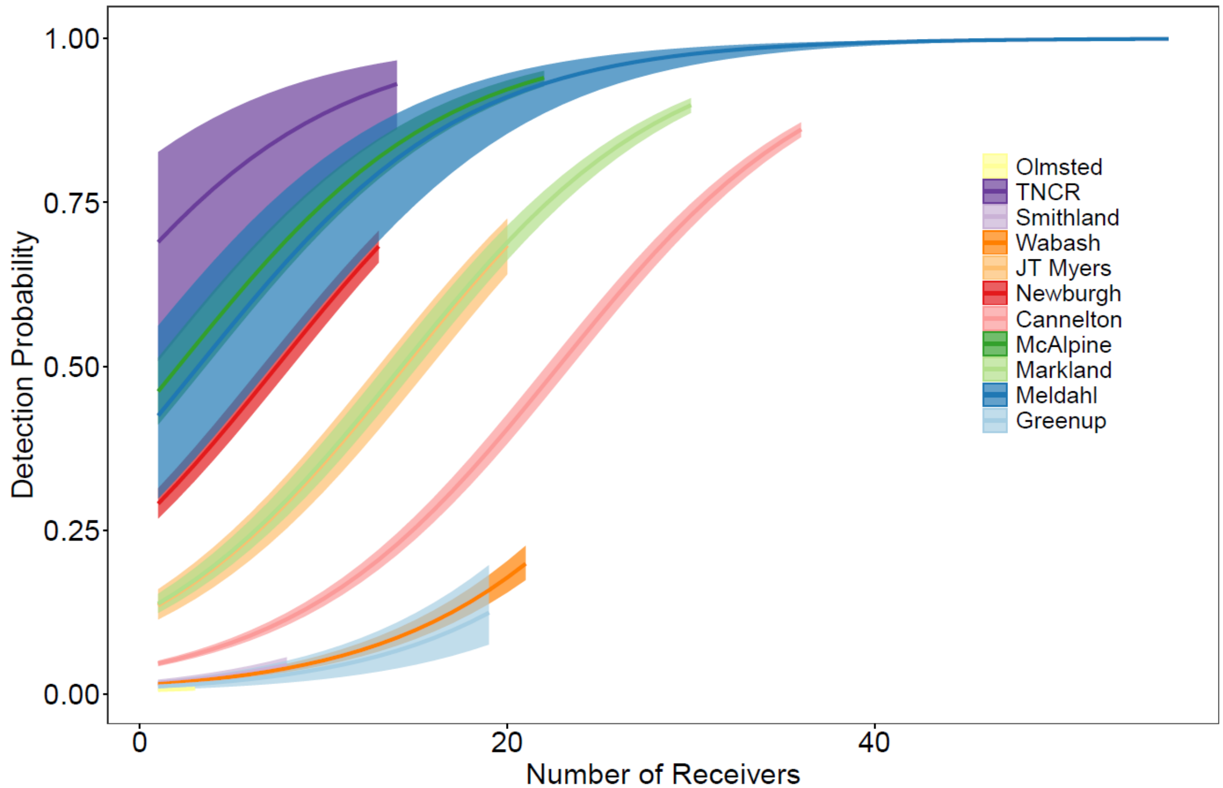

Figure 12. The effect of the number of receivers on the probability of detection (p) of Silver Carps in nine Ohio River pools, the Wabash River, and the Tennessee/Cumberland rivers (TNCR). The number of receivers ranged from 1 to 56 to reflect the number of receivers deployed in each pool during January 2014 – July 2024. The solid lines represent the mean probabilities of detection for each pool, whereas shaded areas represent the 95% confidence intervals surrounding those mean detection probabilities.

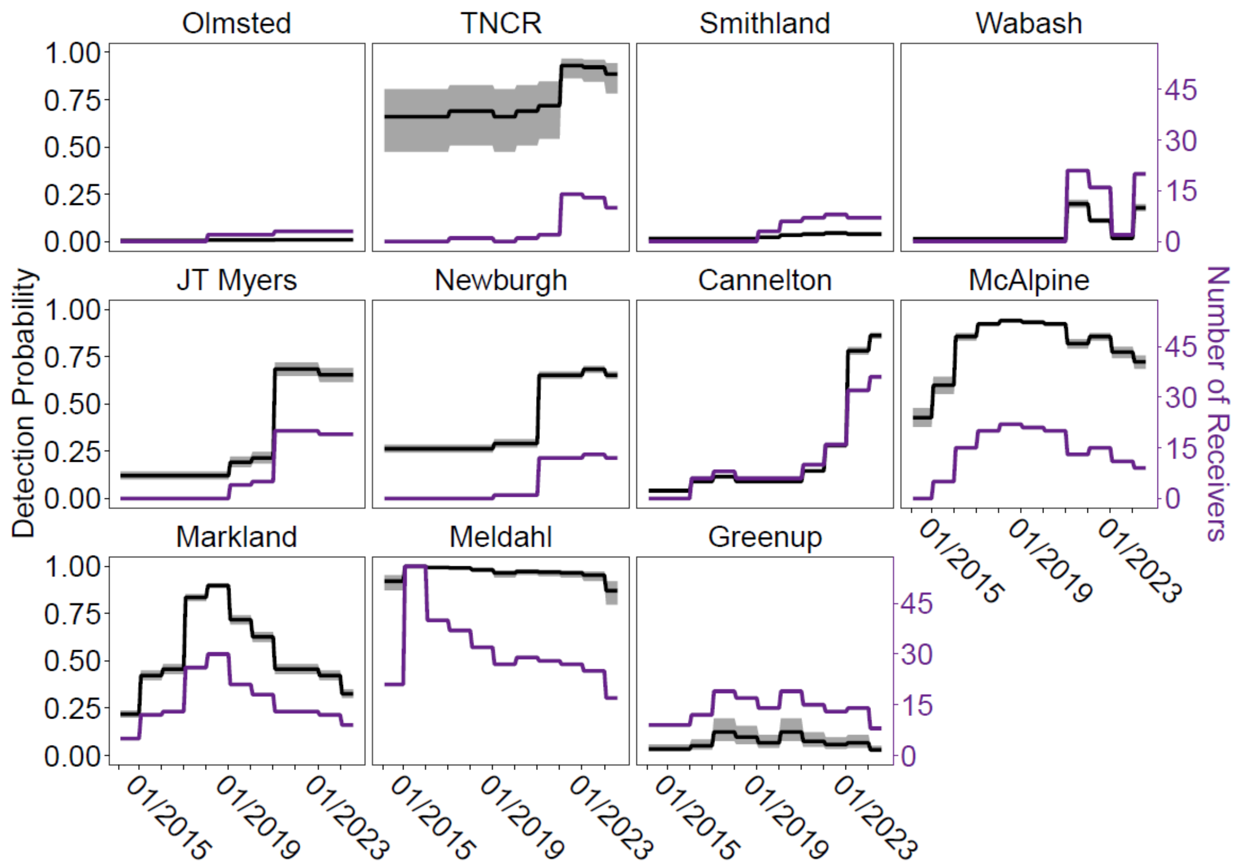

Figure 13. Mean and 95% confidence intervals of the detection probability of Silver Carp (black line and gray shaded area, respectively) and the number of receivers deployed (purple line) during January 2014 – July 2024 in each pool or river within the Ohio River Basin.

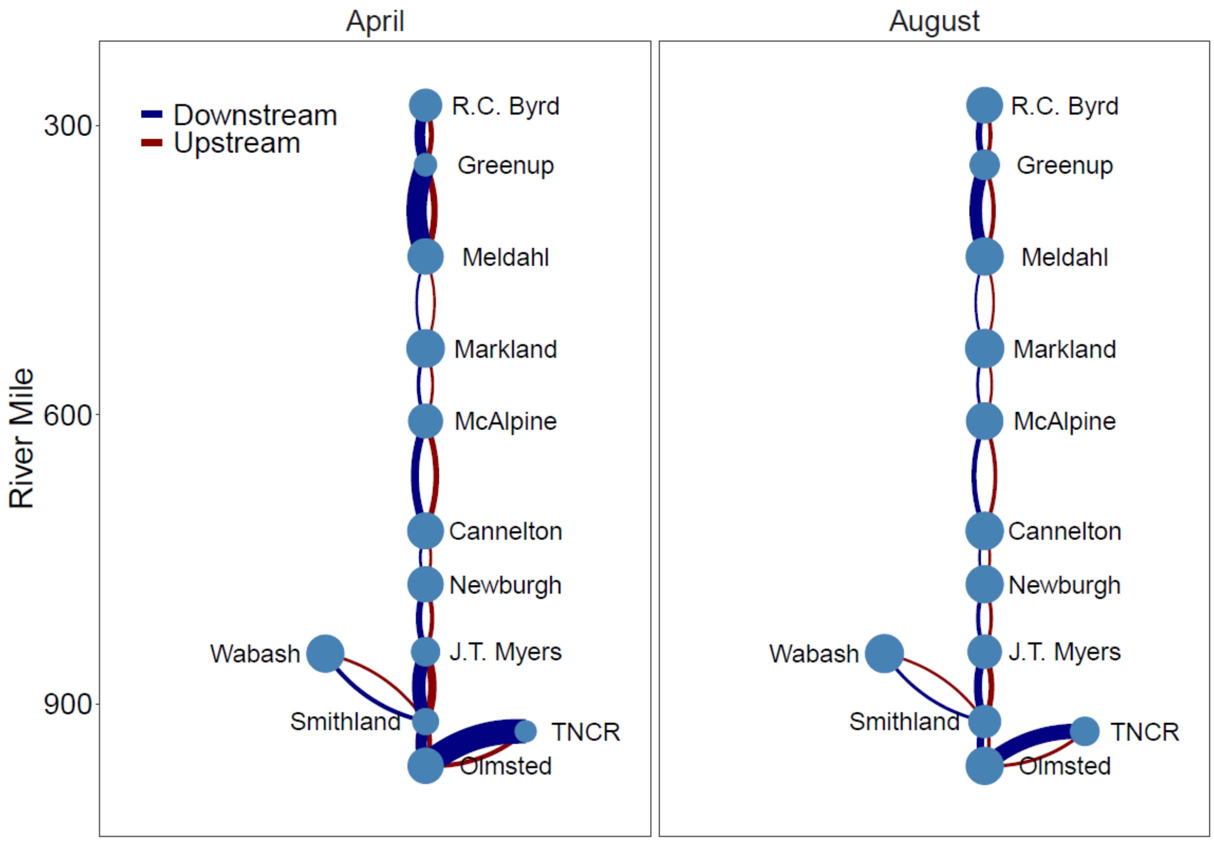

Figure 14. Mean estimated transition probabilities (ψ) among pools and river systems within the Ohio River Basin for April and August. Red lines indicate upstream transition probabilities, whereas blue lines denote downstream transition probabilities. Line thickness is proportional to the transition probability from one area to another. Blue points represent each pool or river and their size is proportional to the probability that Silver Carp remain within that pool during a month. Plots for other months are available from USFWS, CAR FWCO.

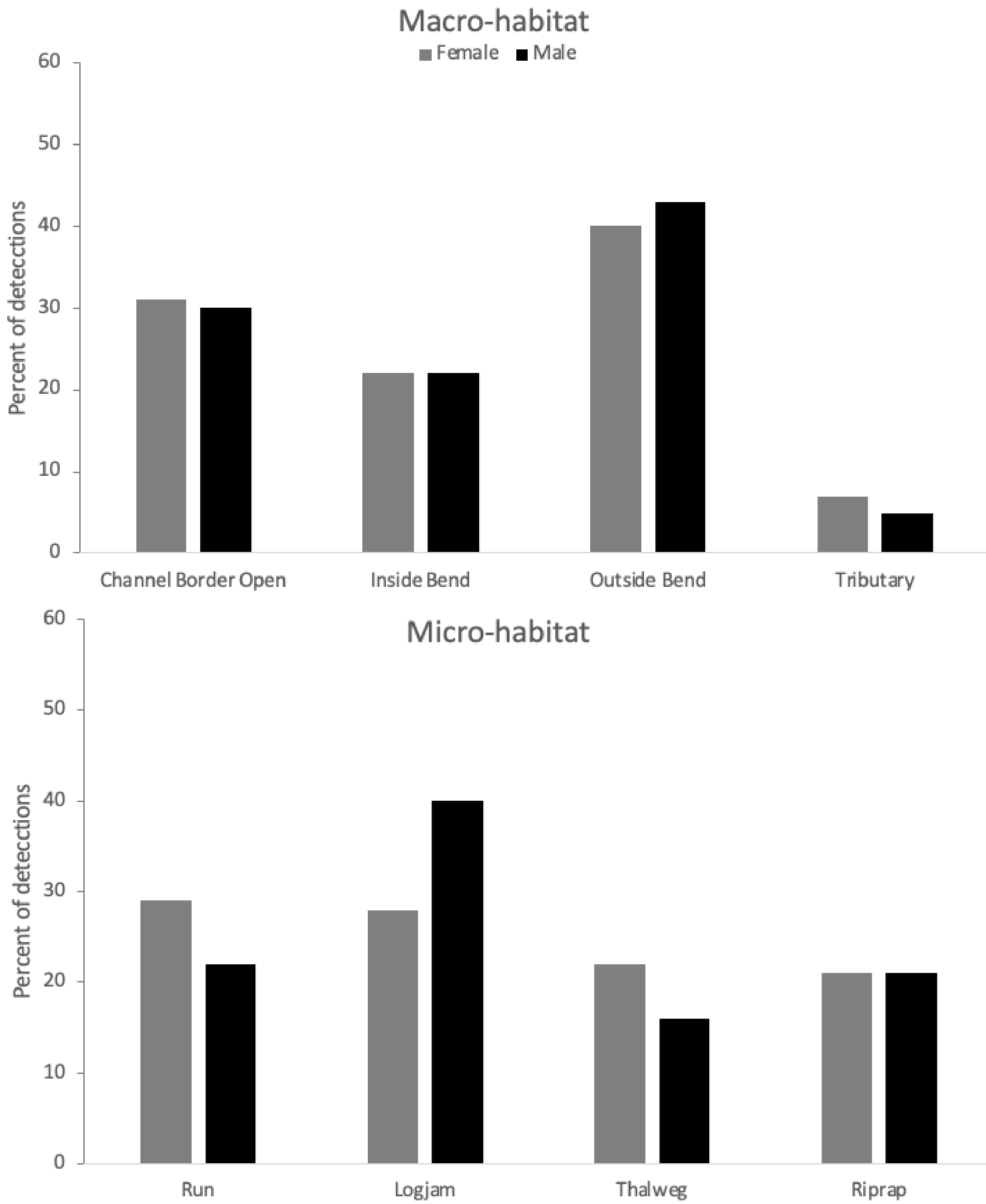

Figure 15. Percent distribution of macro-habitat (top) and micro-habitat (bottom) categories by sex (131 F, 294 M) from active tracking detections (2021-2024).

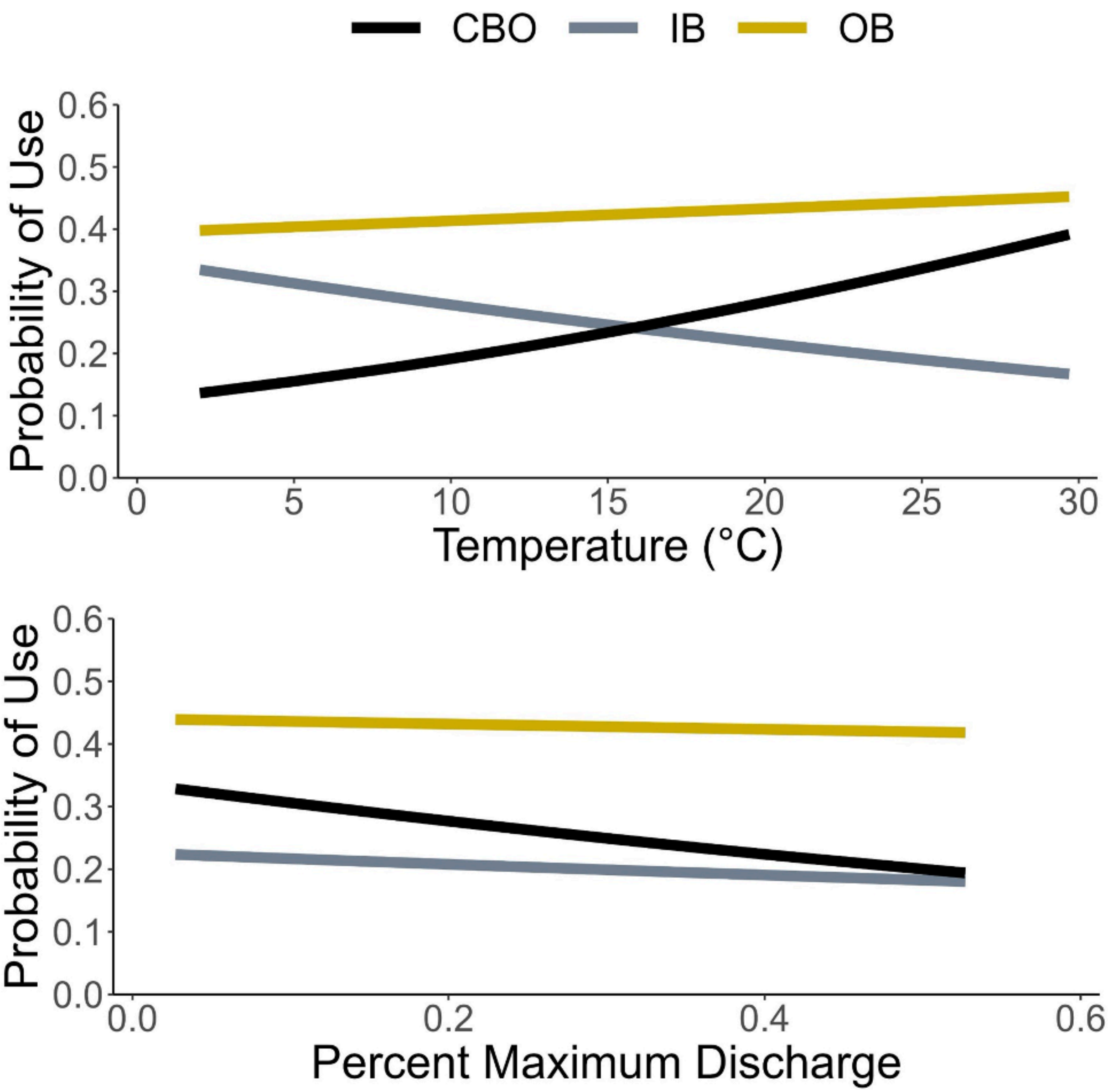

Figure 16. Probability of macro-habitat use logistic regression models based on river hydrological parameters (temperature and percent maximum discharge) for all tagged carp detected for the years 2021-2023. Macro-habitat categories include Channel Border Open (CBO), Inside Bend (IB), and Outside Bend (OB).

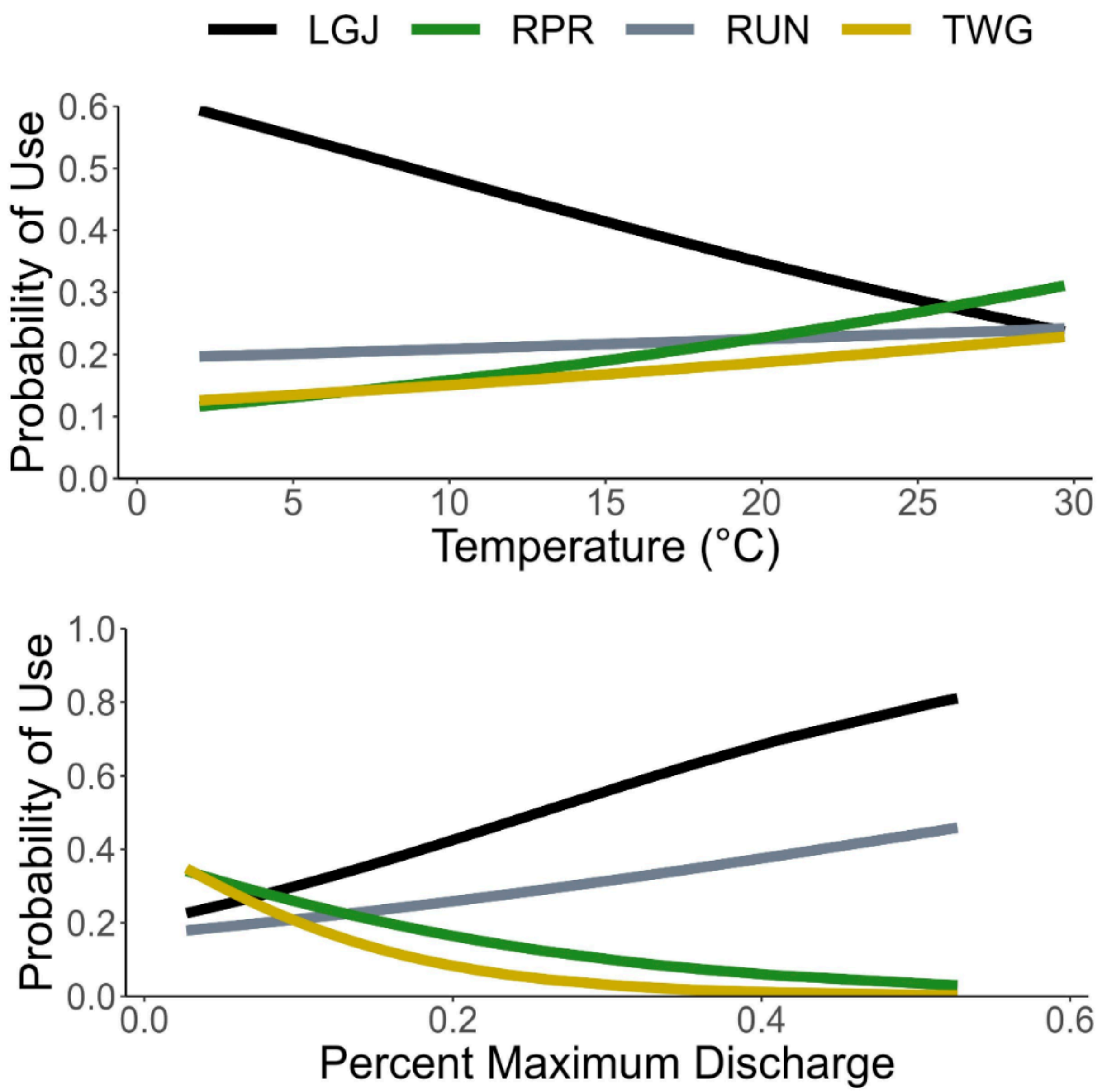

Figure 17. Probability of micro-habitat use logistic regression models based on river hydrological parameters (temperature and percent maximum discharge) for all tagged carp detected for the years 2021-2023. Macro-habitat categories include logjams (LGJ), riprap (RPR), run (RUN), and thalweg (TWG).

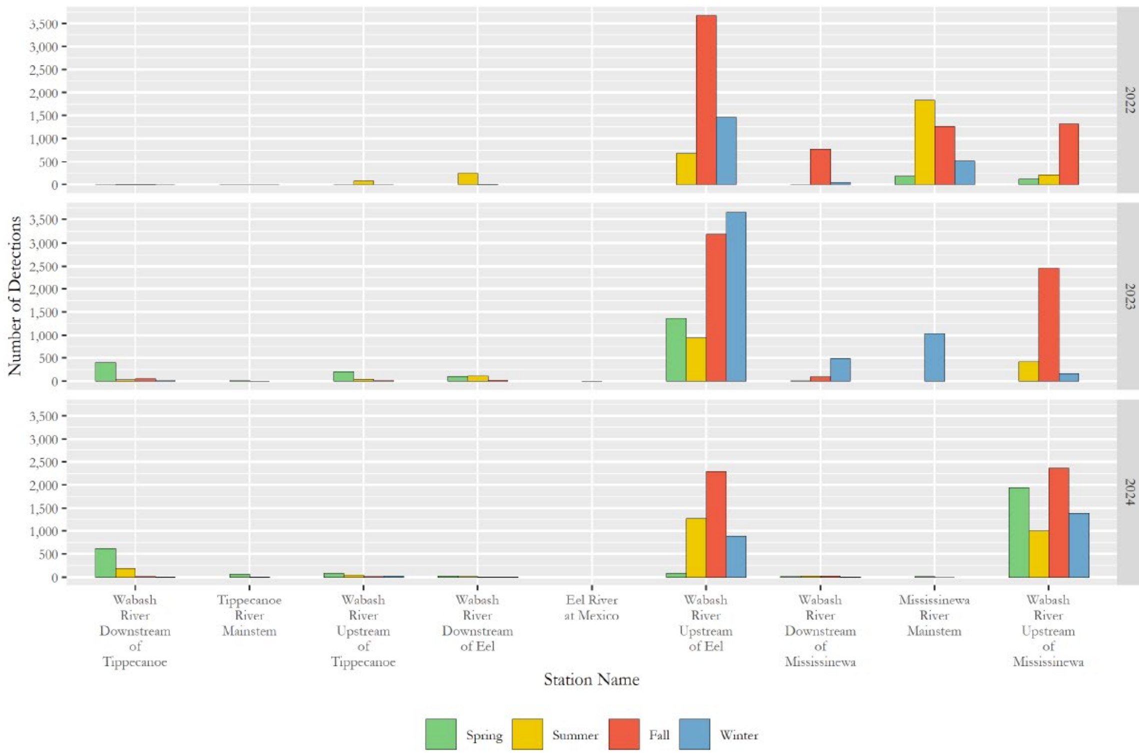

Figure 18. Number of detections of a tagged Silver Carp at each Innovasea acoustic receiver location per season in 2022, 2023, and 2024. No Silver Carp have been detected in the Salamonie River Mainstem or the receivers installed upstream and downstream of the confluence of the Salamonie River with the Wabash River. Season was determined using the meteorological definition of seasons. Receivers were installed in May 2022 and collected data until 18 December 2024 for this analysis.

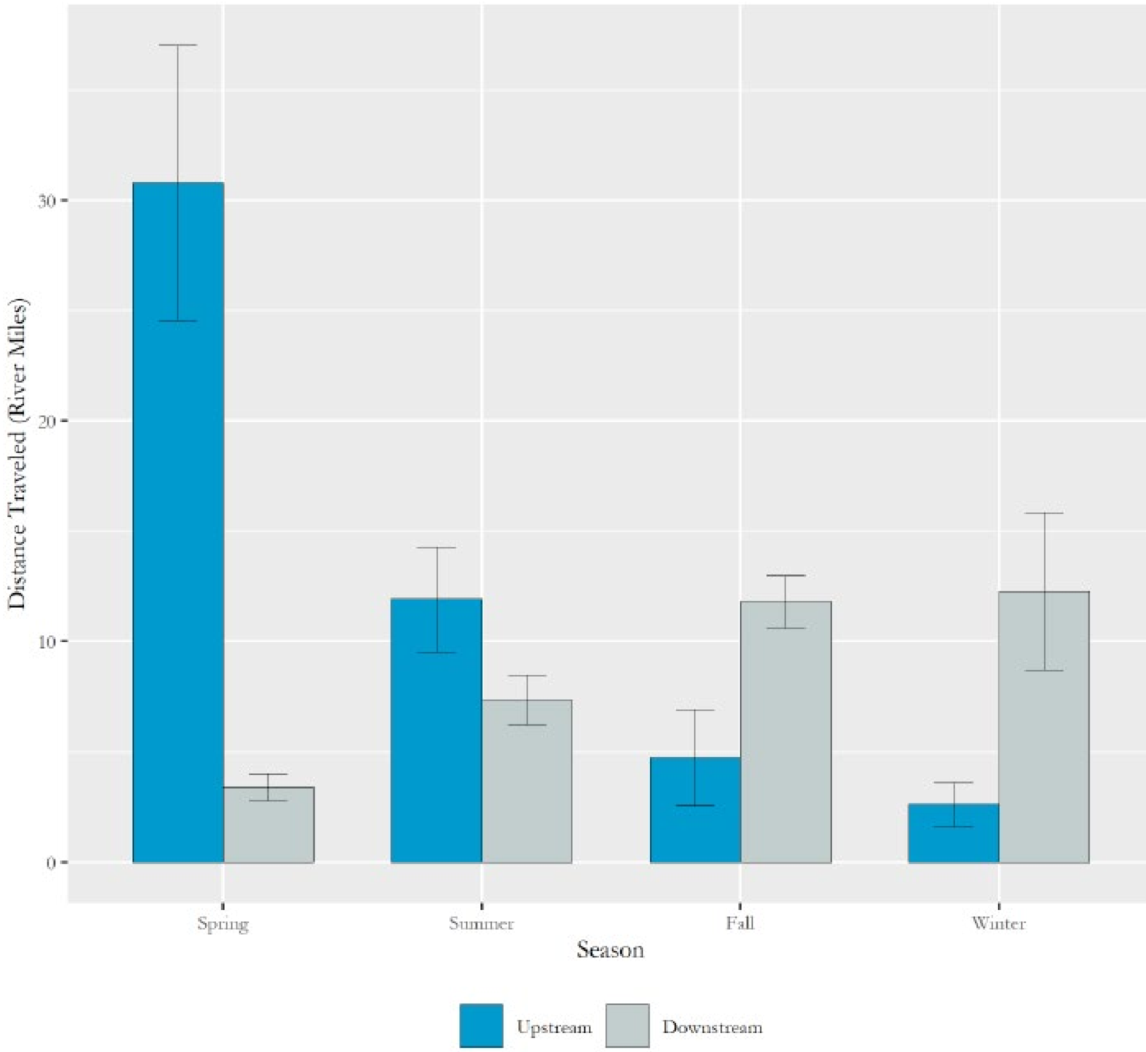

Figure 19. Average distance traveled per season and movement direction in river miles for Silver Carp detected using the network of Innovasea acoustic receivers installed in the Upper Wabash River Basin. Error bars represent ± the standard error from the mean. Season was determined using the meteorological definition of seasons. Receivers were installed in May 2022 and collected data until 18 December 2024 for this analysis.

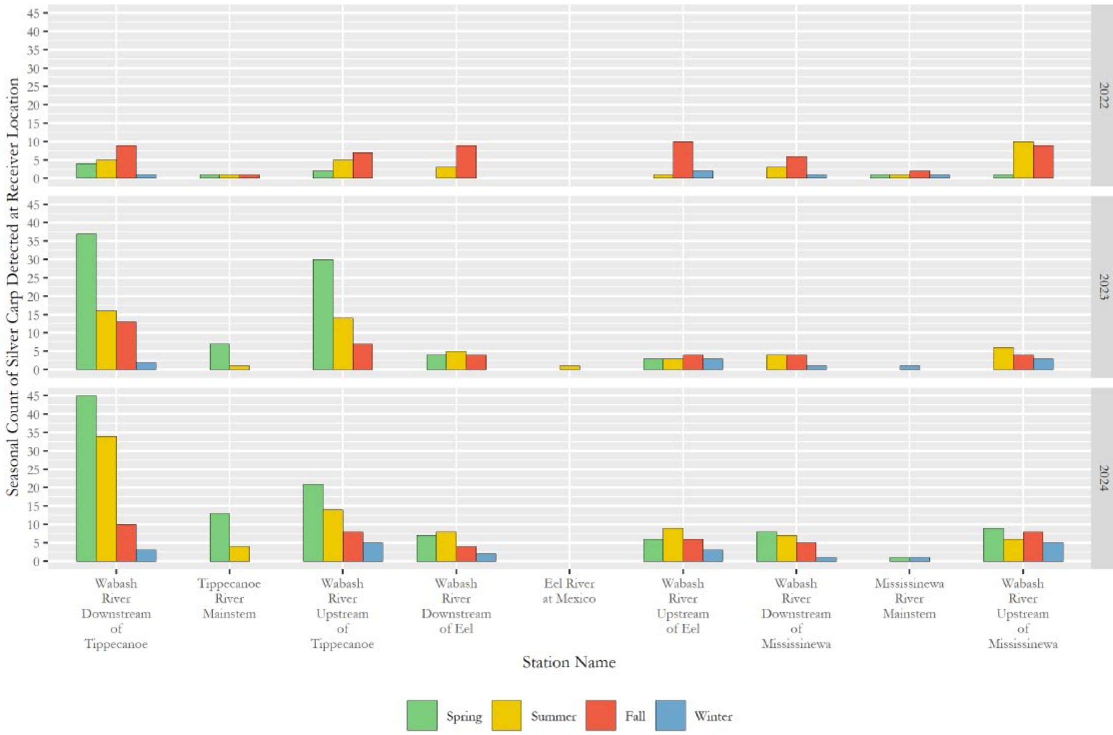

Figure 20. Number of Silver Carp detected at each Innovasea acoustic receiver location per season in 2022, 2023, and 2024. No Silver Carp have been detected in the Salamonie River Mainstem or the receivers installed upstream and downstream of the confluence of the Salamonie River with the Wabash River. Season was determined using the meteorological definition of seasons. Receivers were installed in May 2022 and collected data until 18 December 2024 for this analysis.